THE FUNCTIONAL INERTIA OF LIVING MATTER

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"I CAN find no intelligible ground for refusing to say that the properties of protoplasm result from the nature and disposition of its molecules."—T. H. HUXLEY "On the Physical basis of Life," Edinburgh, November 8, 1868.

"No one who is awake to the tendencies of thought and work in physiology can fail to have observed that the best minds are concentrated . . . upon those questions which relate to the elementary endowments of living matter."—Sir JOHN BURDON SANDERSON, Address to Section of Biology, Meeting of British Association, 1889.

THE FUNCTIONAL INERTIA OF LIVING MATTER

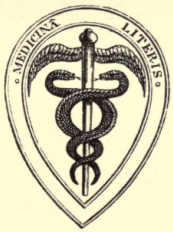
A CONTRIBUTION TO THE PHYSIOLOGICAL THEORY OF LIFE

BY

DAVID FRASER HARRIS

M.B., C.M., M.D., B.Sc. (Lond.), F.R.S.E.

LECTURER ON PHYSIOLOGY AND NORMAL HISTOLOGY IN THE UNIVERSITY OF ST. ANDREWS; EXAMINER TO THE UNIVERSITY OF ST. ANDREWS LL.A. SCHEME; VICE-PRESIDENT OF THE SCOTTISH MICROSCOPICAL SOCIETY; MEMBER OF THE PHYSIOLOGICAL SOCIETY AND ROYAL SOCIETY OF MEDICINE; FORMERLY LECTURER ON PERSONAL AND SCHOOL HYGIENE AT ST. ANDREWS UNDER THE SCOTTISH EDUCATION DEPARTMENT; AND SENIOR ASSISTANT AND MUIRHEAD DEMONSTRATOR OF PHYSIOLOGY, UNIVERSITY OF GLASGOW



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TO

JOHN GRAY McKENDRICK

EMERITUS PROFESSOR OF PHYSIOLOGY IN

THE UNIVERSITY OF GLASGOW

IN EVER GRATEFUL REMEMBRANCE

OF COUNSEL, GUIDANCE, AND

ENCOURAGEMENT GIVEN

TO THE AUTHOR

M371899

PREFACE

One hears nowadays in many quarters cries for a freer exercise of the scientific imagination.

I have, whether consciously or unconsciously I do not know, responded to these repeated stimuli, and have essayed to imagine protoplasm as endowed with a second fundamental property, affectability, of course, being the first.

It is two hundred and thirty years ago since Francis Glisson, M.D., of Cambridge, formally gave us the concept of irritability of living matter, more especially that of muscle.

Biology has since expanded so as to be unrecognisable to the author of the "Tractatus de ventriculo" and in particular to the author of its chap. (vii.), "De irritabilitate fibrarum"; but the potentiality of its growth lay largely in the recognition of this property of excitability (affectability) in living matter. Careful analysis has shown me that a theoretically complete account of the behaviour of bioplasm with regard to the environment and also in consequence of heredity, cannot follow from the assumption in it of only one fundamental property.

I have, for some years, seen that the recognition of *two* physiologically opposite or complementary

properties in protoplasm is of the greatest assistance to the logical perfection of our conceptions regarding the *modus operandi* of the activities of living matter.

Not that I pretend to have got behind molecular structure or disposition—the ultimate inscrutable of biology as of physics, but I hold that by postulating a second fundamental property as residing in the biogenic complex and contributing to its functional complexity, we are afforded a fuller insight than we have at present into what one might call the " true inwardness " of living matter.

[I must here take the opportunity of acknowledging with gratitude the financial assistance I have received from the Carnegie Trust for the Universities of Scotland, in carrying out the experimental work partly described in chap. ii. Certain expenses connected with the publication of these results in the present volume have also been met through the liberality of the Trust.]

D. F. H.

The University, St. Andrews,
October 1907.

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FUNCTIONAL INERTIA

CHAPTER I

GENERAL CONSIDERATIONS ON THE PROPERTIES OF PROTOPLASM

LIVING matter or bioplasm is known to be living in virtue of its possession of a property whereby, if the living matter receives a stimulus, it will *respond* in some way or other to that stimulus—this property is called affectability (irritability or excitability): in German *Erregbarkeit* is the corresponding term.

Affectability can, then, be defined as the power, tendency, capacity, or disposition to be affected by a stimulus, *i.e.*, to *exhibit response*. The response is usually two-fold—(*a*) one or more of the transformations of energy, and (*b*) some re-arrangement of molecules in space.

This property under the name of "Irritability" (*Irritabilitas*) was first attributed to living matter, to muscle, by the anatomist, Dr. Francis Glisson, of the University of Cambridge in 1677.

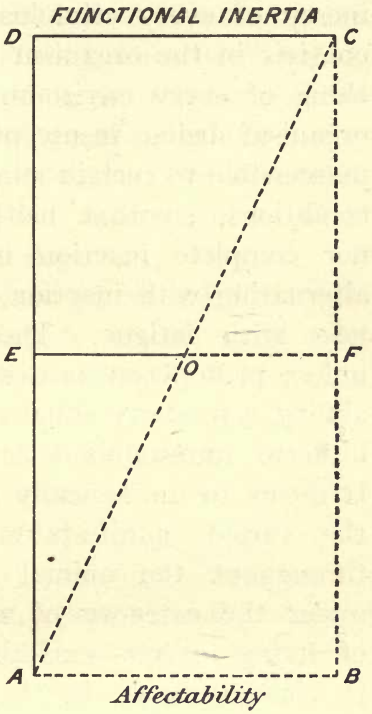
Now life or livingness cannot be adequately described in terms of affectability alone, the possession of no other property than this would allow for continuous response, unending activity—an

eternity of unrest. This is not life as we know it, no organism we know possesses this unqualified, unrestricted, unopposed, infinite affectability, but is on the contrary endowed simultaneously with the physiological counterpart of affectability, viz., physiological *in*susceptibility. Doubtless the results of the possession of this other property have been to some extent, and, under certain forms, recognised by philosophical biologists, but, as far as I am aware, no one has formally asserted what I now do, that livingness consists in the simultaneous possession by protoplasm of two physiologically opposed properties—affectability and insusceptibility—or, as I prefer to call the latter, functional inertia.

I shall presently show how the term arose in my mind as suggested by the inertia of masses, but in the meantime we may speak of this other property in any terms we please so long as they connote physiological insusceptibility, non-affectability. These terms do not, however, cover all that is meant by inertia of protoplasm, so that I prefer the latter; but my point at present is that life, the normal biotonic state in protoplasm, is the result of the simultaneous possession of and due co-ordination between *two* primary properties. Infinite affectability would give rise to infinite activity, ceaseless, unresisted, unresisting eternal action, a mode of life wholly unknown on this planet; while infinite functional inertia would represent eternal death.

Throwing this idea into some kind of diagram we should have two wedges side by side, ABC, and ACD,

ABC representing affectability, and *ACD* representing the opposite property. Along the line *EOF*, you have that state of livingness conditioned by the simultaneous possession of some affectability (*OF*) and some inertia, (*OE*); whereas at *AB*, affectability is maximal, and functional inertia infinitely small; at *DC*, affectability is infinitely small, and functional inertia maximal. This latter state is that of death. There is thus an element of tending towards death at the vital level *EOF*.



And does not all life tend to death; did not Bichât define life as "the sum of the conditions which ward off death," and did not a much older thinker say, "in the midst of life we are in death"?

The Frenchman's pessimism is biologically justifiable. These two vital tendencies or properties of living matter—the one to respond to, the other to be independent of the outer world of stimuli—are inextricably interwoven in the texture of the organism; it is the unravelling of them, to some

extent, that I have undertaken in the following pages.

Life consists as much in the organism corresponding with its environment as in its not being at the mercy of every stimulus it may encounter: life consists in the organism not being the facile plaything of every environmental change, but in the organism being insusceptible to certain changes, inaccessible to certain stimuli, unaffected by certain conditions, so that neither unrestrained activity nor complete inaction is the result, but action alternating with inaction, activity with rest, freshness with fatigue. These things cannot be so unless protoplasm possesses, in addition to affectability, a property equally fundamental with it, and hitherto unrecognised as such, *functional inertia*. It seems to me logically impossible to subsume all the varied manifestations of vitality exhibited throughout the animal and vegetable kingdoms under the category of a single primary property of living matter—excitability. But this is what is virtually done in those text-books where any classification of properties is attempted.

When it is said *† that the vital properties of protoplasm are: power of assimilation, irritability, movement, secretion, automatic molecular changes, reproduction, have we not the enumeration of

* M^c^Kendrick, "Text-book of Physiology," vol. i. p. 33. (Maclehose, 1888.)

† Foster, "Text-book of Physiology," pp. 1–5. (Macmillan, 1877.)

some of the results of the possession of affectability (always excepting automatism, an interesting exception, as we shall see)? From my point of view, irritability is not something in the same category with, not of the same order as movement, secretion, &c., but is more fundamental—a *property* of living matter, in fact, while the other things are *results of its existence*—phenomena or manifestations of vitality. Affectability is rather the essence of vitality on the existence of which these others depend—from which they flow.

To go no further than the phenomena instanced by Foster and McKendrick, I would prefer some such classification as the following:

Essential or Fundamental Properties of Protoplasm.	Vital Manifestations or Results.
(1) Affectability. . .	Assimilation, certain aspects of metabolism, movement, secretion, and reproduction.
(2) Functional inertia .	Automatic molecular changes, certain other aspects of metabolism, *e.g.*, reproduction and rhythmic movements.

I prefer to put it—that certain phenomena are the result of protoplasm being affectable; but we must not mix up affectability with certain of the signs of its existence: it is a causal condition, they are effects, it is an antecedent condition, they are consequences of it. Being affectable, protoplasm responds to a stimulus—the nature of the stimulus being for the present of no moment—and these responses

are that it moves or secretes or produces heat, or external work or electric discharge or all of these together.

Irritability is a general, primitive property depending upon the biochemical configuration of the excessively complicated molecules composing protoplasm ("biogens" of Verworn)—a universal property possessed by all living organisms, organs, tissues, cells in both the vegetable and animal worlds. Its existence is the essence and criterion of life. The amœba as well as the man has affectability, the yeast-cell, the daisy, and the sensitive plant all have it; as a result of its possession, the amœba engulfs the food particle or the poisonous bacterium in contact with it, the man starts when a gun is fired, the yeast-cell "ferments" sugar to alcohol, the daisy opens to the morning sun and closes in the dark, and *Mimosa pudica* folds its leaves with a droop of inimitable grace.

Environmental change or "stimulus" acting on bioplasm possessing affectability, produces a result, a phenomenon, a manifestation of irritability. These several factors should be distinguished, and each given its appropriate place or precedence in the chain of causal occurrences.

But we have not far to seek to discover manifestations of vitality or vital phenomena that can scarcely be thought of as due to environmental change acting on affectable protoplasm.

When we apply a stimulus to a tissue and there is no response for a time varying from $\frac{1}{100}$th of a second to several seconds, when we find in other tissues a

total disregard of our stimulus, a refractory period, a period of complete insusceptibility; or on the other hand when we find an organism doing a thing not in the least as the result of a stimulus, but "spontaneously" or "automatically," when we find the organism in possession of a power or tendency to hold on the even tenor of its metabolic way, to act in a particular manner when the external conditions would constrain it to act in some perfectly different manner, we cannot attribute these things to affectability. Although as a *term*, inertia of protoplasm, is metaphorical or at least borrowed from the realm of physics, I intend it to be used as a technical term for the physiological opposite of affectability. Undoubtedly physiologists have already recognised "physiological insusceptibility" as a vital phenomenon; but, as a concept, "physiological insusceptibility" is not coextensive with functional inertia; this insusceptibility is but one mode of expression of the possession by protoplasm of the fundamental property of functional inertia.

How the term arose in my mind may be gathered from what I * said at the meeting of the British Medical Association at Ipswich in August 1900: "There are two kinds of inertia as properties of matter (*a*) the inertia of matter at rest, and (*b*) the inertia of matter in motion. That property of matter in virtue of which it tends to maintain its state of rest or of uniform motion in a straight line, is called its inertia. The existence of inertia is the

* D. F. Harris, *Glasgow Medical Journal*, April 1901.

postulate in Newton's First Law of Motion—'Every body continues in a state of rest or of uniform motion in a straight line, except in so far as it is compelled by forces to change that state.' It is by reason of its inertia of rest that we find it difficult to move the massive gate swung on hinges of even relatively very small friction, there is, in other words, 'lost time' before the response begins; on the other hand, once we have set the great gate swinging, it will move through a considerable angle after we have ceased to push it; this is due to its inertia of motion or momentum."

"We have as biologists been so much impressed by the universality of that property of living protoplasm irritability or affectability, the power of responding to a stimulus, that it is just possible we have underestimated a property no doubt of less importance but still of interest which I venture to call 'functional inertia.'" I then proceeded to define it as that "property of protoplasm whereby the living matter contrives to remain in a functional *status quo ante*, notwithstanding that it has received a stimulus, or, having responded to the stimulus, it continues to exhibit its functional activity for a certain time after the stimulus as a form of energy has ceased to exist. Living protoplasm furnishes us with examples of inertia which might be called that of function." This was written at the end of 1899: since then I have become so convinced of the truth of it that I would alter none of it except the phrase in parenthesis—"no doubt of less importance"—to, "no doubt of vast importance."

Just as you cannot at once get the great door into movement so neither can you instantaneously arrest its swing, it keeps on moving by its momentum after the arresting force has begun to be applied. Under certain conditions, therefore, activity and not inactivity may be the expression of protoplasmic inertia: continued activity after, say, an inhibitory stimulus has been applied and for the time being disregarded—post-stimulant activity, and also when activity has been in progress and the causal stimulus has been removed, the activity continues post-stimulant—both are cases of maintenance of the *status quo ante*, that is, are inertial. Conversely, under certain conditions, inhibition—partial or complete arrest of activity—may be an expression of affectability. Protoplasmic activity, which is not the result of the impinging of stimuli, which is not due to environmental influence and is exhibited even under conditions tending to suppress it, is inertial: under this head come certain factors in spontaneity and automatism. Thus we may have—

Either activity
or
Inhibition of activity
} arising from affectability;

and conversely,

either non-response in disregard of stimulus, if inactivity is the *status quo ante*,

or

response in disregard of stimulus, if activity is the *status quo ante*,

} arising from functional inertia.

This point is somewhat important because the term inertia being etymologically related to "inert" may in time come to be used in a functional sense as denoting only those cases of inactivity after a stimulus—physiological insusceptibility in fact. It is obviously only this form of inertia which is strictly the physiological counterpart of affectability. This would be an unfortunate limitation of the usefulness of the term on the one hand, and of the symmetrical correspondences with the phenomena of affectability on the other.

Take the case of the heart: through its possession of affectability it can be either accelerated or inhibited, that is, inactivity can be the result of stimulus acting on an affectable organ; but, conversely, through its possessing functional inertia, the heart will for a time disregard a stimulus arriving during its refractory period, or, being stimulated by induction shocks of, say, 50 a second, will perform its rhythmic movements at a vastly slower rhythm than that, one having no causal relation to that of the stimuli whatever. In the same way on being heated, the rapid action cannot be forced beyond a certain rate (1.5 per second in the frog, 6 per second maximum in the rabbit). This idio-muscular activity, this activity independent of stimulation, is inertial. Thus though the heart possess affectability, there are the most rigid limits set to its expression, limits which prevent its being tetanised, being hurried beyond a certain pace, limits also to the energy of its systole. Here then

is action, but it is limited action, action that cannot be accelerated beyond certain limits, at a pace that cannot be forced, at a degree of energy that cannot be exceeded; this is an expression of functional inertia: through pure affectability as the only property of cardiac protoplasm, such things could not be. "The tissues set the pace," as the author of the chapter on the Respiratory Exchange * writes with regard to the inability of tissues to perform respiratory exchanges at a greater rate than a certain fixed one known as "the normal," and again, "rapid breathing does not bring about a greater total exchange of gases than does slow breathing." There is a tissue-pace which cannot be voluntarily hurried. Again in the same work, in the chapter on Purin Excretion † we are told that the endogenous purin excretion is constant for each individual, and does not depend on any *known* physiological condition of the individual—the unknown here is functional inertia. We shall find that inertia sets limits in connection with many other phenomena, some of which will be subsequently dealt with. These limits set to metabolic possibilities are due to the possession of functional inertia —a property possessed contemporaneously with affectability. Thus the manifestation of life at any given instant is to be regarded as the resultant of two co-existing but physiologically opposite functional propensities or capabilities, the degree of whose

* "Recent Advances in Physiology and Bio-chemistry." Edited by L. Hill, p. 484. (London: Arnold, 1906.) † *Ibid.* p. 403.

relative intensities conditions the character of the particular manifestation at the moment—response, if affectability be the predominating condition, non-response if functional inertia be the characteristic state. Non-correspondence with the environment is the keynote of this protoplasmic inertia, independence of environment, disregard of stimulation, inaccessibility to external influences, all insusceptibilities, and limits set to powers of response.

Just as the idea of a stimulus without the corresponding organism to act on is meaningless, so conversely a property of protoplasm thought of as unrelated to a stimulus is jejune; or otherwise, property and stimulus are so co-related that what may be relatively to one stimulus a state of affectability, may be, at the same moment, to some other stimulus one of inertia, and *vicè versâ*: and again, what may be a state of affectability at one time to a particular stimulus, may be one of inertia at another time to the same stimulus. Affectability is, in fact, a term for our conception of the relationship between the living matter and that stimulus which is causal in the manifesting of a response; and in one of its aspects, functional inertia is our conception of such a relationship as leads to no response; and lastly, under its other aspect, functional inertia is our conception of the relationship whereby, after the stimulus has ceased to act, the living matter continues to act.

Biotonus or the biotonic state is the particular result of the state at any given moment resulting from

the two oppositely but simultaneously proceeding phases of metabolism, anabolism and katabolism. So, too, the precise state of the vital manifestations at any given moment is the result of the degree of intensity of affectability and of functional inertia possessed at that moment by the living matter in question. For each property must, or at any rate may, vary from moment to moment: each may vary absolutely and relatively to the other, and in some way the intensity of the possession of these two simultaneously varying factors at any given moment must be related to the particular inter-relations of the two simultaneously proceeding metabolic phases. This relation between the properties and stimulation may be illustrated by definite example. Wedensky * has shown that glands which would not secrete when stimulated by very strong electrical stimuli, would do so if much weaker stimuli or stimuli at a slower rhythm were resorted to. There was insusceptibility towards stimuli above a certain maximum of strength and above a certain optimum of rate. (Wedensky remarks on the secreto-motor latent period in all these cases.) Similarly, von Kries and Sewall † have found that in cooled nerve, electric oscillations of 100 per second failed to produce tetanus, the initial twitch alone being produced. I have noticed the same thing at room temperature in the muscles of the abdominal somite of the lobster.

* Wedensky, *Compt Rend.*, vol. cxv. 1892, p. 1103.

† Sewall, *Journ. Phys.*, vol. ix. 1898, p. 92.

Here there is a definite insusceptibility to a series of stimuli, a lack of correspondence between responses and stimuli. There are, in short, a number of variables to be taken into account at the same moment, viz., the two metabolic phases, the two fundamental properties, and the stimuli. I follow Verworn when he defines a stimulus as "Every change in the external vital conditions of an organism." Under this head constant stimuli, such as condition of the blood, would not seem to be included, but the definition should be enlarged to admit of this, since blood is, for cells, one of their external conditions, and for some cells it is a varying stimulus, for instance, as regards its varying amounts of oxygen and of carbon dioxide. Stimuli may be classified after Verworn * as

(1) Those tending (*a*) to increase or (*b*) to decrease anabolism ; + A and − A and

(2) Those tending to (*a*) increase or (*b*) to decrease katabolism ; + K and − K.

In the appendix to this chapter a scheme of the relationships between these various factors is given in full.

The principle involved may be stated thus :

Protoplasm in predominant anabolism on receiving a stimulus tending to cause it to change its state qualitatively (that is a positive katabolic stimulus) will, if affectability be predominant, begin to katabolise, but will, if functional inertia be

* Verworn, "General Physiology," p. 357. (London : Macmillan, 1899.) † *Ibid.* p. 490.

predominant, continue to anabolise, that is, to maintain the functional *status quo ante.*

As a concrete example we might take the case of an animal resting or very sleepy; it receives a stimulus tending to wake it, if affectability be predominant it will awake, but if functional inertia, it will remain sleepy. We might speak of this latter as anabolic inertia or the inertia of anabolism. Taking the complementary case, the wakeful animal; it receives a stimulus tending to calm it, to put it to sleep, that is, a positive anabolic stimulus; if affectability predominate it will become less restless, if functional inertia it will continue alert and wakeful, that is, the *status quo* is maintained, but in this case activity is the result of the inertia which might be called katabolic or the inertia of katabolism.

Several authors, without going to the root of the matter, have used the term "inertia" or "resistance" in connection with the behaviour of living beings. Thus the late Sir Michael Foster * wrote "inertia or laziness" in *Nature*, June 22, 1893, and Loew † uses the expression "the different degrees of resistance of protoplasm" which is surely the exact opposite of affectability. Professor Mosso speaks of "the inertia felt in the muscles of the legs after a long walk" ‡ and more lately Dr.

* Foster, *Nature*, vol. xlviii. p. 178.

† Loew, *Pflüger's Archiv.*, 1885, vol. xxxv. p. 509.

‡ Mosso, "Fatigue," translated by Dr. Drummond, p. 227. (Sonnenschein, 1904.)

Marcus * in his little *brochure* on "Monism?" uses such an expression as "that tendency to persist," which means the impossibility for any given cell at any time to become any other kind of cell. This same author speaks (p. 117) of "an organism which showed such a capacity for resistance:" *that* is not meant to convey affectability.

If it is objected that the assuming of the existence of functional inertia "explains too much," it must be remembered that the same objection militates equally against the conception of affectability. For certainly affectability explains, or rather as a property underlies, a vast and quite heterogeneous assemblage of functions or phenomena, viz., movements of all kinds, evolution of heat, of electricity, the doing of internal and external work, secretions of the most diverse composition, excretions equally so, 'tropisms and 'taxes of every description. If functional inertia explains many and different things, so in truth, too, does affectability; but the fact is, that, strictly speaking, neither property explains anything in the sense of giving the reason why when a stimulus is received energy is or is not transformed by the living protoplasm: whereas in another sense, these properties afford the only explanation we can have until the day when we know in terms of the conceptions of organic chemistry what biogenic instability and

* Marcus, "Monism?" translated by Dr. Felkin. (Rebman, 1907.)

stability respectively mean. The incidents expressible by vitality must be as diverse and as widely scattered throughout organic nature as are the capabilities and potentialities of living matter. There may be, I believe there are, as many manifestations of functional inertia as there are of affectability; neither property can explain too much; between them they have to explain the whole realm of vitalised existence; and if *they* do not do so, nothing else at present is capable of doing it. To neither property alone can the multitude of vital phenomena be logically referred. If there be a property of inertia such as I have described, it should be capable of demonstration in the cell, in the tissue, in the organ, in the system, in the organism, in the species, in the nation and in the race. It must underlie psychological as well as physiological facts, mental behaviour as well as bodily conditions. There must be a metabolic inertia expressible in the vital unit as well as in the vital whole—the animal or plant, and in the social unit as well as in the social whole—the community or race.

[I need hardly say that living organisms have inertia of mass, inertia in the ordinary sense. It is due to our mass (inertia of rest) that we fall backwards when the electric car starts suddenly and owing to our inertia of motion (momentum) that we fall forward when the car stops suddenly. By our inertia of mass in motion, we fall forwards if our foot catches in an obstacle when we are running, and in this way a child trips more readily than an adult owing to its centre of gravity being relatively a good deal higher—due to the greater relative size and weight of the head in the child. I need scarcely say, finally, that the

movements assumed by the Mach-Crum-Brown theory to be taking place in the endolymph and perilymph in the internal ear, and so constituting stimuli for equilibration, are again cases of *molar* inertia.]

APPENDIX

When the Biotonic state is characteristically	and the stimulus is	Then the property being	The phenomenon is
Anabolism .	+ A	affectability	increase of state of rest.
		functional inertia	state of rest continues in *status quo* (latent period).
Anabolism .	+ K	affectability	a response begins.
		functional inertia	latent period (no response during).
Anabolism .	− A	affectability	diminution in intensity of existing state.
		functional inertia	*status quo* maintained (latent period).
Anabolism .	− K	affectability	inactivity proceeds.
		functional inertia	ditto.
Katabolism .	+ A	affectability	action begins to diminish.
		functional inertia	action continues: post-stimulant activity.
Katabolism .	+ K	affectability	increase of vigour of activity.
		functional inertia	(the *status quo* maintained); stimulus neglected (refractory period).
Katabolism .	− A	affectability	activity begins to diminish.
		functional inertia	stimulus disregarded (latent period).
Katabolism .	− K	affectability	activity begins to diminish.
		functional inertia	latent period.

CHAPTER II

FUNCTIONAL INERTIA EXPRESSED AS LATENT PERIODS, LIMITS, INSUSCEPTIBILITIES AND RHYTHMS

THE phenomenon known as "latent period" is, under the time-category, an expression of the possession by protoplasm of functional inertia: "Physiological lost time" is perhaps a better term. All cases of this in unicellular organisms I take to be manifestations of protoplasmic inertia.

With reference to light as a stimulus, certain Protistæ do not, for some measurable time, exhibit the positive or negative phototropism of which they are capable.

In regard to ciliary activity—a very primitive function—Verworn,* writing of a ciliated infusorian, Pleuronema chrysalis, says, "the motion of the cilia does not begin at the exact moment at which the light strikes, but only after 'a latent period' of from one to two seconds." Certain ciliated infusoria exhibit no affectability towards light at all, with reference to this stimulus their functional inertia is infinite—complete physiological insusceptibility.

* Verworn, "General Physiology," p. 401. (London: Macmillan, 1899.)

Passing on to tissues, we have the familiar latent period of muscular tissue, shortest for striated muscle of warm-blooded animals, longer for heart-muscle, longest of all for non-striated fibre. In other words, the fibre with least anabolic inertia has most affectability (striated), that with most inertia has least affectability (non-striated), and heart-muscle occupies an intermediate position. As judged by the duration of post-mortem life, a point which will be discussed later on, the non-striated fibre has most and the striated least katabolic inertia, the myocardium again occupying an intermediate place.

(I have seen a frog's heart beating after four minutes' immersion in " Ranvier's $\frac{1}{3}$ alcohol.")

Latent period undoubtedly exists in other tissues of the animal—in gland, and in the nerve-cells, both of spinal cord and of cerebrum.*

In all cases in which the stimulus is nerve-impulses which have travelled through any length of nerve before impinging on the tissue in question, the true latency of the tissue is the difference between the total physiological lost-time and the time taken by the impulse to travel from the point of origination to the nerve-endings in fibre or cell.

The latent period for secretion by the pancreas through stimulation of the vagus, *e.g.*, is very long (15″ to 3′, Pawlow). Now the time of travelling of nerve-impulses is very short (at least 30 *metres* a second) so that even when the time for transit through

* Gotch, " Text-book of Physiology." Edited by Schäfer, Vol. ii. chap. on " Nerve," p. 451.

the maximum length of vagus is deducted, it leaves in this case an exceedingly long physiological lost time (so long in fact that this has been suspected of being the time occupied by preparation of secretin).

Latent period exists in capillary endothelium as shown in Lord Lister's early experiments on the response of capillary wall to chemical and other irritants. The wall of the vessel does not at once respond to the stimulus of the mustard which at first tends to make it contract, but only after an interval—a measure of the functional inertia of this tissue.

The lengthening of the latent period in fatigued muscle is interesting ; in fatigue, inertia is increasing and one expression of this is the increase in the physiological lost time.

Vegetable protoplasm exhibits physiological latency very strikingly. Mr. R. A. Robertson, lecturer on Systematic Botany and Vegetable Physiology at the University of St. Andrews, to whom I had suggested seeking for examples of inertia in vegetable protoplasm, writes on this point.* "A change in one or more of the external conditions induces a growth variation, but not all at once, there is a period of non-responsiveness, of accommodation, of anabolic inertia, and the duration of this period varies with the stimulus, *e.g.*, the time-value of the anabolic inertia is less for a temperature-change than for one of oxygen-pressure or food-

* R. A. Robertson, "On the Functional Inertia of Plant Protoplasm." P.R.S.E., Session 1901–1902. Vol. xxiv. Part iii.

supply." "In heterauxesis, induced by lateral stimulation, by gravity, light or heat, there is a latent period before the geotropic, heliotropic or thermotropic curvatures begin to be manifested. This latent period—that of anabolic inertia—may be of any length from a few minutes for geotropism to a few hours for thermotropism." . . . "To wound-stimuli, growing as well as adult organs exhibit non-responsiveness in varying amount. Thus, traumatropic curvature in growing roots is only manifested after a latent period of anabolic inertia of half an hour or so, and this period may be artificially lengthened to as much as eight days. Here, as in other cases where a sense-organ has been demonstrated, transmission time has to be deducted from the (total) latent period to get the duration of the anabolic phase."

Now with regard to latent period, it is on this view virtually a refractory period, so that the refractory period of cardiac muscle *is* its latent period of contraction. I find this is the view taken by Professor Gregor Brodie * in discussing the inability to tetanise the heart: it is the inertial phase that is the cause of this inability. The heart cannot be hurried beyond a certain pace: tetanising stimuli no doubt accelerate its rhythm a little, but a limit is soon reached. Professor Brodie remarks that as tetanic stimulation is continued, the cardiac refractory period is lengthened, *i.e.*, the inertia is

* T. Gregor Brodie, "Essentials of Experimental Physiology," p. 111. (Longmans.)

increasing. Fig. 1 shows tracing of the heart of a rabbit beating in hot salt solution (NaCl): it cannot be induced to beat beyond about six times per second as a maximum.

The cells of the central nervous system have a

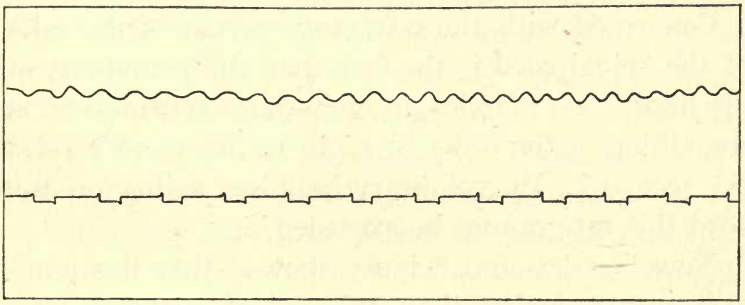


FIG. 1.—Upper line: tracing of ventricle of heart of rabbit beating at maximal rate in hot "normal saline" solution, six a second maximum. Lower line: half seconds.

measurable and very distinct latent or refractory period, demonstrated for cerebral cells by Richet,* for those of the spinal cord by Horsley and Schäfer.†

Sir Victor Horsley ‡ expressly points out, as important in the diagnosis, the very long latent period in the central nervous system after "shock." The symptoms of traumatic neurasthenia may be so long in becoming apparent, that certain clinicians have been led into the error of asserting that the neurasthenia was actually *not* caused by the so long antecedent injury.

These refractory periods set the limits to the rate of discharges from the central nervous system,

* Richet, *Nature*, October 26, 1899.

† Horsley and Schäfer, *Journ. Phys.*, vol. vii. p. 96.

‡ Allbutt's "System of Medicine," vol. viii. p. 166.

they underlie a large number of neural disabilities. Some of these are such as not being able to articulate more than a certain number of syllables per second (10 to 11 per second), or to perform more than about the same number of muscular twitches per second with, *e.g.*, the finger or the hand.

Connected with the refractory period of the cells of the spinal cord is the fact that the periodicity of discharges to muscles in voluntary contraction is something of the order of 10 to 12 (up to 18 rarely) per second.* By voluntary impulses acting on the cord this rate cannot be exceeded.

Now Horsley and Schäfer showed that if stimuli at any rates higher than this spinal inherent rate, say, of 50 a second were imposed on any part of the encephalo-spinal tracts, the spinal discharges were still at no greater rate than before (10 to 12 a second).

Supposing, therefore, that it was ascertained that the rhythm of discharge of voluntary impulses from the cerebrum was something greater than 10 to 12 a second, this would nevertheless be transmuted by the functional inertia of the cells of the cord into a much slower one, so slow that it could never fully fatigue the muscles as is possible with the high frequency stimulation of experimental tetanus. Thus there is a neural, as well as a muscular, insusceptibility which prevents exhaustion.

Professor Schäfer † in his article on "The Nerve

* D. F. Harris, "The Time-Relations of the Voluntary Tetanus in Man," *Journ. Phys.*, vol. xvii. No. 5, 1894.

† "Text-book of Physiology." Edited by E. A. Schäfer, vol. ii. 1900, p. 614.

Cell" does not hesitate to use the word "inertia" in connection with refractory period of nerve-cells. To this inertia he attributes the fact that the second of two stimuli arriving within a "certain fraction of a second" is disregarded, and that if two different sense-organs are simultaneously stimulated, two sensations are not perceived; there must be an interval of time greater than a certain minimum between the two (differential time) in order that both sensations be appreciated. These remarks I had not seen when I wrote my first paper.

Refractory period or period of neural insusceptibility must underlie all such phenomena as insensitiveness to increments in strength of stimulus as is involved in the Weber-Fechner Law, non-response to maximal stimuli, insensitiveness to stimuli beyond the limits in which the Law is applicable, and several other phenomena involving consciousness which will be taken up in the chapter on psychic inertia.

The central nervous system affords us many examples of the inertial property: this ought not to surprise us in a system in which functional differentiation has been carried so far. In it we have a wide range of graded responses towards environmental stimuli, and also a not less interesting series of all kinds of non-responses, insusceptibilities, and latencies. Certain idiosyncratic insusceptibilities of the nervous system towards drugs, come under this head; for instance, the considerable differences in susceptibility to nicotine, alcohol, morphia, cocaine. The

ganglia of the cat have much inertia towards nicotine ; those of the rabbit little, but even in any one animal Professor Langley has shown that great variations in responsiveness exist in the different ganglia.

Insusceptibility has long been recognised in, *e.g.*, the uterus by gynæcologists who speak of "uterine inertia" when they find that the organ does not contract on the fœtus after a drug has been given quite as quickly as they would like. The term is accurate : this uterine inertia is the greater according as affectability is the less, *e.g.*, in women no longer young.

But Dr. Hale White * has extended the term to the alimentary canal and speaks of "colonic inertia" —"congenital inertness" of the colon—an equally defensible expression.

In Dr. Sharkey's Presidential Address to the Neurological Society (Feb. 4, 1904) † I came across the expression, "the functional inertia of nerve-cells . . . in the cord," and again, "the inertia of cells of the cord." Dr. Sharkey, writing to me in February 1905, kindly informed me in answer to my inquiry, that when he composed the address he did not know of my views. His use of the very terms I had suggested four years previously is an indication of their usefulness as I had predicted ; but I now go farther and say that it is the possession by living protoplasm of the property of inertia that has given

* Hale White in Clifford Allbutt's "System of Medicine," vol. iii. p. 971.

† Dr. Sharkey, *Brain*. Spring number, 1904, p. 11.

rise to the necessity for the concept as embodied in these terms.

One more example of the use of the term inertia in connection with the nervous system I should like to quote, viz., that by Dr. A. D. Waller in his article, "On the functional attributes of the cerebral cortex." * He writes, "The impulse influences cellular energy . . . it tends to overcome or actually overcomes inertia, and in the latter case it effects friction." . . . "I imagine the greater instability of the cell to be *molecular*, so that the disturbance by a second impulse can propagate itself with less diffusion, overcoming less chemical inertia, and producing less friction than the disturbance produced by a first impulse."

Later on in the same paper, resistance in nerve-cells is defined as "chemical inertia." I quote these passages to show how thinkers-out of physiological problems are constrained sooner or later in their analyses, to come to the notion of inertia of the living molecules. Whatever else Dr. Waller desires to convey in the very searching analysis to which he here subjects neural processes, he desires to convey this, that there is a property of inertia possessed molecularly by nerve-cells and expressed in chemical phenomena: this is functional inertia.

Dr. Mercier † in writing of the cells of the nervous system explicitly says, "the molecules . . . oppose increased *inertia* to the efforts of errant currents."

* A. D. Waller, *Brain*, parts iii. and iv., 1892, p. 329.

† Mercier, "Sanity and Insanity," p. 305.

A very interesting chemical expression of functional inertia is seen in the inability of certain fungi to ferment certain sugars.* Thus if certain yeasts be placed in a mixture of l-fructose and d-fructose, the latter will be attacked, the former left untouched. These are stereoisomers, and except by the difference in their treatment of polarised light, *i.e.*, difference in the grouping of the atoms in their molecules respectively, they are chemically indistinguishable.

Now the vast majority of the sugars occurring in nature are dextro-rotatory or derived from a dextro-antecedent whereas the lævo-sugars (except ordinary levulose) are new—the results of comparatively recent syntheses. The yeasts know nothing of these l-sugars, they are not accustomed to them, they disregard them utterly, their functional inertia towards them is maximal. They are not yet educated to be susceptible to sugars to which their ancestors were completely unaccustomed. The possibility of their being educated to ferment a sugar, to which at first they were inert, has been demonstrated.†

An interesting example of a limit set to cellular metabolism is that lately demonstrated with regard to oxygen-pressure on cells.‡ Within very wide limits, the rate of cell-metabolism is not hurried by excess of oxygen-pressure: "the tissues set the pace" and set limits beyond which no further

* Bernthsen, "Organic Chemistry," 1894, p. 309.

† Dubourg, *Comp. Rend.*, vol. cxxviii. 1899, p. 440.

‡ Hill and Co-writers, "Recent Advances in Physiology an Bio-chemistry," p. 237. (London: Arnold, 1906.)

activity, no activity at any higher potential is permitted—this is functional inertia.

A very familiar example will illustrate the limit-setting nature of functional inertia in the organism as a whole. A certain piece of manual labour is to be done: the labourer who is to be paid by time takes, we shall say, eight hours to "the job," works at a low potential and does not get very tired at the end of it; the same piece of work could be done by an enthusiastic amateur in one-third of the time; he would exhibit much less inertia, work at a much higher potential and be correspondingly exhausted.

On the subject of limits Dr. Maudsley writes in the following suggestive way:

"It is a mistake, however, to say . . . that heat and external conditions determine the rate of growth. The rate of germination, for example, certainly varies according to external conditions, but the *limits* of variation are *fixed* by the *inherent properties* of the structure." * Dr. Maudsley † in this passage means exactly what I do when for "properties" I substitute—"the property of functional inertia," &c.

"The seeds of a begonia taken from the same pod will, as Mr. Paget has pointed out, germinate some in a day, some at the end of a year, and some at various intermediate times, even when they are all placed under the same external conditions; and the same author has pointed out other indications of self-dependent time-rates in the lower organisms. There

* The italics are mine.

† H. Maudsley, "Body and Mind," 1870, p. 171.

are, in fact, internal as well as external conditions of growth, and the former are the more important for they are really the determining conditions. It is with the organic cell and its conditions as it is with the individual and his circumstances; the latter may greatly modify character and are necessary for development, but the essential fact, which determines *the limit* of the modifying power of circumstances, is the nature implanted in the individual." This is a most interesting presentation of what I mean by functional inertia as limit-setting.

Rhythms.—I regard all natural or spontaneous rhythms of centres, *e.g.*, the respiratory, the vasomotor, &c., as examples of phenomena in which functional inertia is a causal factor. Not, of course, that the rhythm in the intact animal and all the characteristics of the discharges from the respiratory centre are altogether inertial; on the contrary, the affectability of the centre is conspicuous as regards voluntary impulses, heated blood, CO_2, poisons, &c., but its functional inertia is none the less obvious. For instance, its uncontrollability by voluntary impulses is significant: we can only, for a minute or two, cease to breathe (voluntary apnœa), and conversely we can accelerate the pace of breathing only to a certain rate beyond which it is impossible to go. No doubt cerebral refractory period as above alluded to is a factor limiting the rate of output of cortical impulses; but the rhythm of the respiratory centre is its own, voluntary impulses are comparatively powerless over it, so that a more detailed examina-

tion into it may be profitably made especially as its experimental physiology has been pretty well worked out.

I shall first quote the view of Professor Starling,* in which an account of the rhythmicality of the centre is given in which it is desired to do without the conception of inertia. "The stimulus derived from the blood is, under normal conditions of respiration, constant. The stimulus derived from the afferent nerves is subject to rhythmical variation and . . . this variation is of considerable importance for the maintenance of the normal respiratory rhythm. The centre can, however, go on discharging rhythmically in the absence of any afferent rhythmic stimulation" (double vagotomy is here alluded to). "We have, therefore, to discuss how the centre is able to respond to a constant stimulus with a rhythmic discharge. The simplest explanation of this process, if explanation it can be called, is to say that it is a property of the nerve-cells as of the muscle-cells of the heart to respond to a constant stimulus by a series of rhythmic discharges. Pflüger considers that the molecular processes in a living cell may be divided into two sets—those which tend to produce a discharge of energy and those which tend to prevent a discharge. In more modern terms we might speak of these two processes as katabolic or dissimilative and as anabolic or assimilative. In a condition of rest these processes balance one another exactly.

* Starling, in "Text-book of Physiology." Edited by Schäfer. Vol. ii. p. 291. (Pentland.)

"The effect of applying a stimulus to the cell is to increase the metabolic processes. In order that those excitatory processes may prevail against the inhibitory, it is necessary that they should attain a certain superiority above the latter. As soon as this condition is reached the excitatory processes break through the resistance of the inhibitory, and an explosive discharge is the result. After the discharge, the inhibitory processes are in the ascendant, and the stimulus from without has to continue acting for a further length of time before the excitation can gather fresh strength to break again through the resistance. This speculation, in default of a better, has played a great part in the speculations of physiologists on the nature of inhibition and the production of rhythmic activity. It suffers, however, as was pointed out by Gad, from the drawback that the molecular processes have to be considered as endowed with *inertia, otherwise* * as soon as the excitatory are in excess of the inhibitory processes, there would be a leaking discharge, and a constant stimulus would cause a constant activity."

Later in the chapter (p. 292) Professor Starling writes: "Under normal conditions this constant stimulation may be afforded by:

"(1) The sum of afferent impulses arriving at the centre.

"(2) The venosity of the circulating blood.

"(3) The normal metabolic change in the nerve-cells."

* Italics are mine.

(Factors 2 and 3 are regarded as underlying the oxygen-hunger of the cells of the respiratory centre.) I may perhaps say that I saw vol. ii. of Professor Schäfer's text-book after my first paper was written.

Here we have the explicit statement that this intermittency of discharge from the respiratory centre *could* be accounted for on the supposition that the "molecular processes were endowed with inertia": but, as Gad has regarded this endowment or property in the light of a drawback, the supposition is not made.

I must frankly say that I see no reason to regard the possession by protoplasm of inertia as any more of a "drawback," than the possession by non-living matter of the same property. If we are logically constrained to attribute inertia to protoplasmic molecules, no preconceived idea about its being a drawback must interfere with our reasoning. Of course in the light of my investigations into these phenomena, I cannot but hold that this functional inertia does exist, and in the case before us *is* one of the causal factors of the intermittency or rhythm.

Before disposing of the case of the rhythm of the respiratory centre, I would like to allude to the relationship between constant stimuli and response. If affectability *were* the only protoplasmic property, then "constant stimuli" should only give rise "to constant activity." But this is precisely what in a number of cases does not happen—constant stimuli giving rise to rhythmic or at least intermittent responses.

The cases I have investigated are those of applying to the sciatic nerve of the frog's nerve-muscle preparation the following constant stimuli, viz., continuous pinching, dry sodium choride, allowing it to dry; and the following instantaneous stimuli, the sudden abolition of anelectrotonus, and sudden

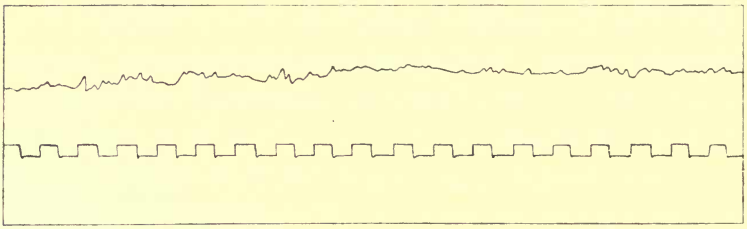


FIG. 2.—Upper line: record of tremor of frog's gastrocnemius muscle when sciatic nerve was stimulated by application of dry sodium chloride—average periodicity 6 to 8 per second. Lower line: half-seconds.

heating of the nerve, all of which give rise to tremors of the gastrocnemius of an average periodicity of from 4 to 6 a second. The muscle itself responds similarly if through it a constant current be made, altered in strength (Wundt's tetanus) or broken, or if it be immersed in Biedermann's fluid, *i.e.*, it breaks off into a tremor of from 4 to 6 a second periodicity.

Thus in the affectable neuro-muscular mechanism we have a non-correspondence between stimulus and response—a constant stimulus giving rise to rhythmic responses, an instantaneous or single stimulus also giving rise to rhythmic responses of the same periodicity; the non-correspondence I take to be due to inertia, and as the non-correspondence is rhythmic or intermittent, I take the rhythmicality

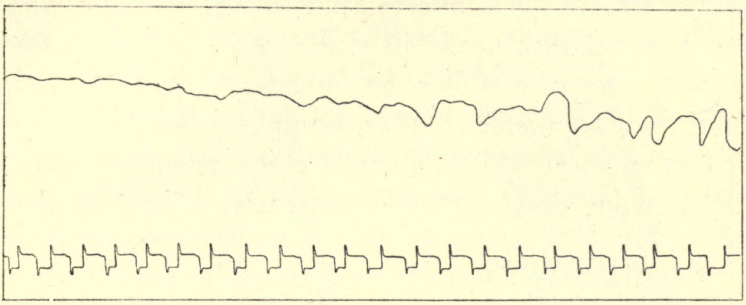


FIG. 3.—Upper line; record of tremor of frog's gastrocnemius when its nerve was allowed to dry—average periodicity of tremor 4 per second. Lower line: half-seconds.

or intermittency in these cases to be a manifestation of the inertial property.

It is interesting that the "spontaneous" rhythm of such a tissue as the dying diaphragm is of the same

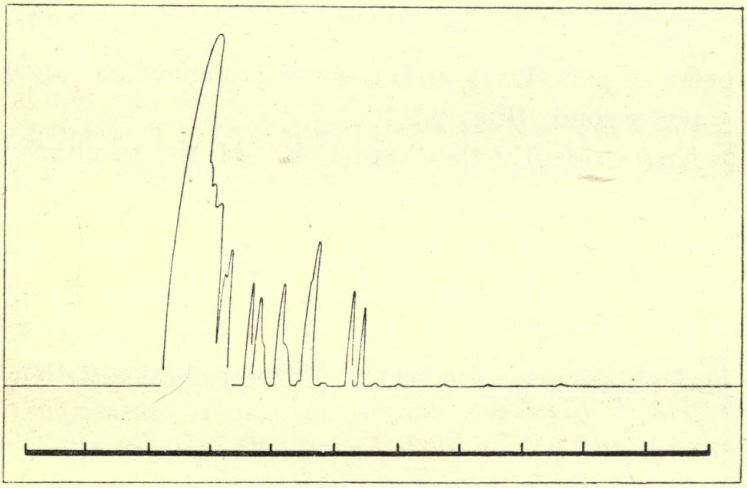


FIG. 4.—Record of tremor of frog's gastrocnemius when the state of anelectrotonus was suddenly abolished in the sciatic nerve—average periodicity 5 to 6 per second. Lower line: time in seconds.

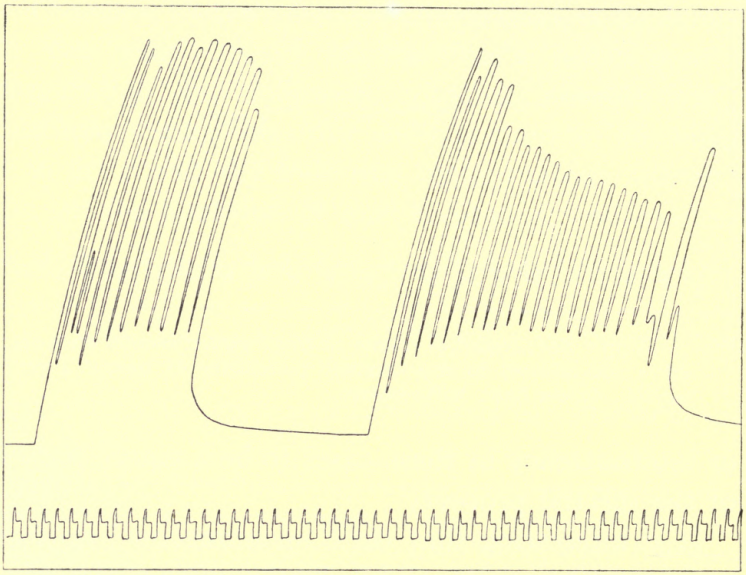


FIG. 5.—Record of contractions of frog's gastrocnemius produced by suddenly establishing a strong constant current through 1 cm. of the sciatic nerve—average number, 3 to 4 per second: time in half-seconds.

order of periodicity as the above; somewhere about 5 per second. (Fig. 7.)

Now evidently the "function" of the respiratory

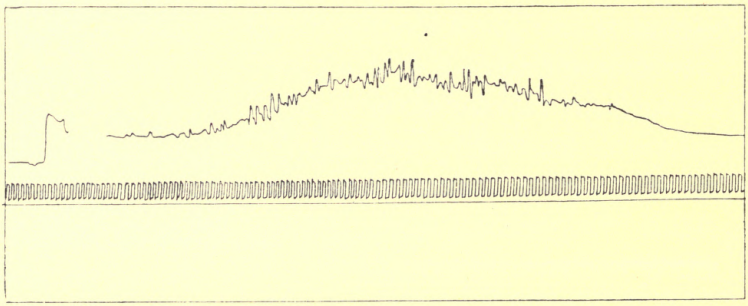


FIG. 6.—First line: record of tremor of frog's sartorius immersed in Biedermann's fluid (sodic chloride, phosphate and carbonate) —average periodicity 3 to 4 per second. Second line: time in half-seconds.

centre is the emission of discharges intermittently and not as "constant activity." Supposing that the blood *is* a "constant stimulus," the centre could through its inertia behave with regard to this in the same way that the neuro-muscular mechanism behaves with regard to constant stimuli, viz., by rhythmic discharges. But it does not need an environment at all—neither blood nor other stimuli—

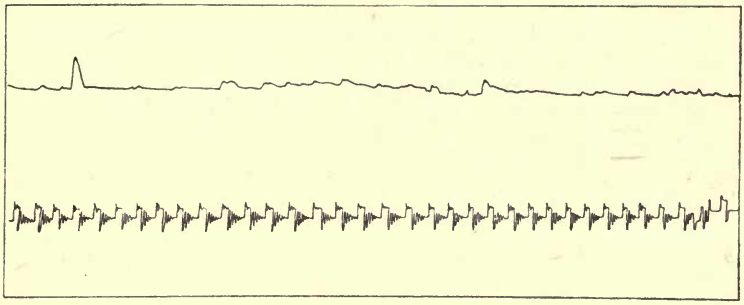


FIG. 7.—Record of tremor of dying diaphragm of the rabbit; both phrenics cut—average periodicity, 5 per second: time in half seconds.

to enable it to discharge intermittently, since Marckwald * has shown that in an eviscerated marmot respiratory spasms were still observed. Of course this state of matters cannot be kept up, death ensues owing to lack of nourishment, but rhythmic discharges, in the absence of all stimuli, are an evidence of the inertial factor in the behaviour of this centre. Doubtless double vagotomy and transection through the Pons Varolii cut off the avenues of arrival of nerve-stimuli intermittent in character,

* Marckwald, "The Movements of Respiration," translated, (London: Haig, 1888.)

and we do then approximate to the state of matters in which the centre is influenced by the " constant "

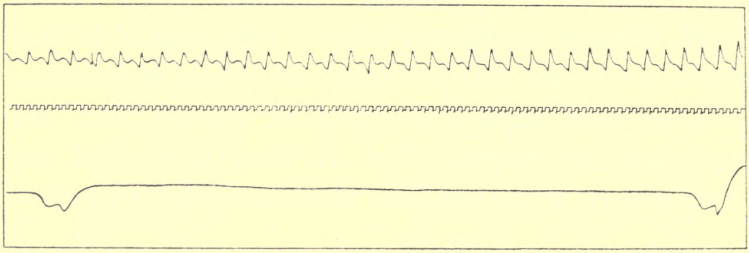


FIG. 8.—First line: record (through diaphragm) of normal respiratory rhythm of puppy (anæsthetised with A C E mixture). Second line: time in half-seconds. Third line: record (through diaphragm) of respiration of same animal after section of both vagi nerves. (Reduced to $\frac{2}{3}$ natural size.)

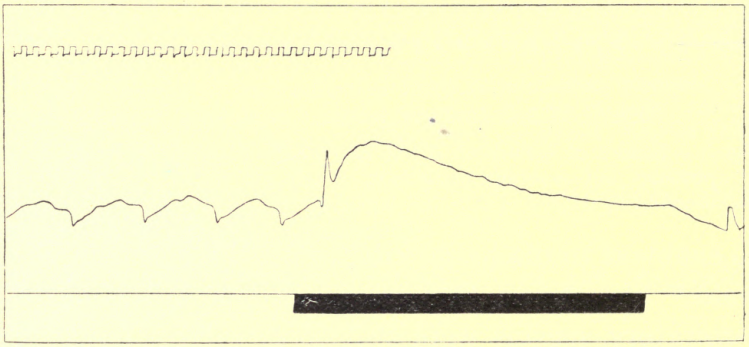


FIG. 9.—First line; time in half-seconds. Second line: record of movements of diaphragm of puppy (under A C E mixture). Third line: at commencement of black mark central end of one vagus was stimulated, "inspiratory tetanus" of diaphragm resulted.

stimulus of venosity of blood alone: the rhythm of discharge is now very slow (Fig. 8).

The superior limit of discharge from the respiratory centre can be reflexly brought out by " tetanic " stimulation of the central end of one vagus, when (with intact phrenics) the diaphragm is held down

in "inspiratory tetanus" in a tremor of about 3 or 4 a second periodicity (*cf.* Fig. 9). Now superior limits are inertial.

I am far from saying that Pflüger's account could not be brought into line with my views provided the inertia of living molecules be granted: I would then prefer "predominant katabolism" to "excitatory processes" and "predominant anabolism" to "inhibitory processes." Further, I think, that "normal metabolic process" should not itself be identified with stimulus, since the former is the state of the material on which the latter operates. Thus I believe that for the maintenance of the normal respiratory rhythm both the fundamental properties are responsible, affectability on the side of response, and functional inertia on the side of disregard of stimuli, the existence of limits, and inherence of spontaneity in rhythm. The physical analogy in the case of rhythms is the pendulum or the rocking-stone or the person on the swing; once started they continue in their own particular periods, alternately exhibiting the inertia of position and that of motion.

I have the sanction of no less a physiologist than Professor Angelo Mosso for the attributing of inertia to the respiratory mechanism. Thus, speaking of the alterations in respiratory rhythm consequent on warming and cooling animals he writes*: "There is, therefore, a degree of *inertia* in this apparatus for reducing the temperature by means of the respiration, for an animal placed in a much

* A. Mosso "Fatigue," translation of "La Fatica," p. 114.

hotter atmosphere does not all at once respire with greater frequency, nor after return to the normal temperature does the dyspnœa cease immediately."

Here Professor Mosso most clearly describes first the anabolic and then the katabolic or post-stimulant inertia, and I would have included this example in the next chapter which deals more in detail with

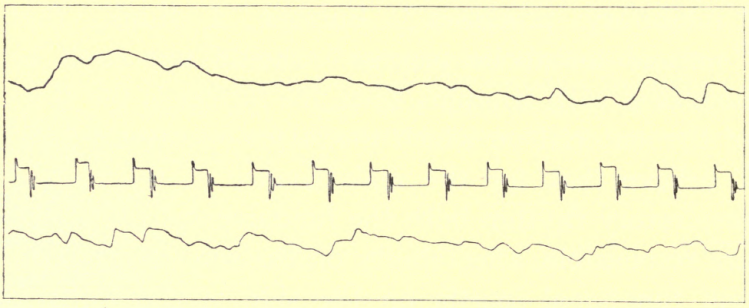


FIG. 10.—First and third lines: records of the post-tetanic tremor of frog's gastrocnemius muscle stimulated through the sciatic nerve—average periodicity 5 to 7 per second. Middle line: time in half-seconds.

such phenomena, did I not here desire to show that the idea of inertia of the respiratory centre has received the sanction of high authority. I need not say that, as Mosso's book was published in 1904, I did not obtain any assistance from it when writing my first paper.

Another type of rhythm is that of the post-tetanic tremor which I have lately investigated.

This is seen in muscles completely tetanised until fatigue sets in, when often quite suddenly the muscle breaks off into a tremor of relatively slow periodicity, 4 to 6 a second. This tremor I have called post-

tetanic : in certain cases (frog and man) it can be maintained for a relatively long time, half an hour. In this state of fatigue we have a non-correspondence between rate of stimulation and rate of response : the ratio is of the order of 4 to 1 or 5 to 1 (frog's gastrocnemius and flexor sublimis digitorum of man) : functional inertia is here a factor.

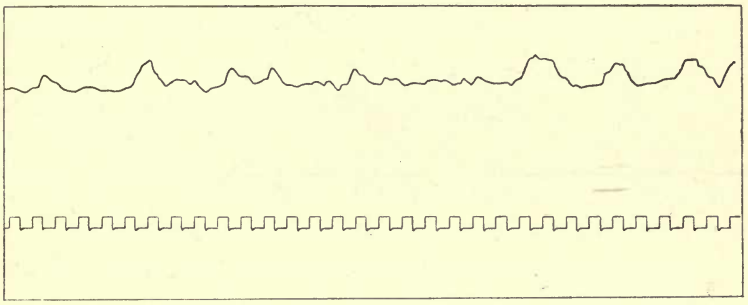


FIG. 11.—Record of post-tetanic tremor of human muscle (flexor sublimis digitorum). Average periodicity 4 to 6 per second : time in half-seconds.

Such a muscle as the frog's mylohyoid which is tetanised by ten impulses per second, *i.e.*, has less affectability than the gastrocnemius, exhibits a post-tetanic tremor of correspondingly slower periodicity, viz., 2 a second ; but the ratio 10 to 2 is the same (5 to 1).

By affectability the gastrocnemius muscle keeps pace with the increasing rate of stimulation from 1 a second to 30 a second, when the limit is reached ; thereafter any stimulation at 30 per second or higher, gives rise to a tremor of no more than 4 to 6 a second —this is the expression of functional inertia through a rhythm.

The muscle of so lowly a creature as the lobster behaves under rapid stimulation in an analogous fashion. Fig. 12 shows that a state of tremor sets in almost from the very beginning: its affectability is not equal to keeping pace with the stimuli (28 a second at least), its inertia, its stimulus-disregarding power is so considerable that it responds

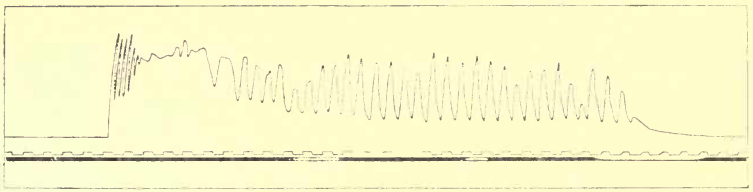


FIG. 12.—First line: record of contractions of muscle of abdominal somite of lobster stimulated by "tetanising" stimuli (third line)—average periodicity 3 per second. Second line: time in half-seconds. (Reduced to two-thirds natural size.)

only 3 to 6 times per second; but as fatigue sets in the responses are at such intervals as every 2, 3, 4, 5, or 6 seconds.

So that in any one neuro-muscular mechanism constant stimuli, instantaneous stimuli, stimuli of relatively high frequency all give rise to the same average periodicity of tremor, *non*-correspondence is obvious here: affectability alone can hardly be expected to explain it.

Fatigue is then a state of partial functional disability related not to affectability but to functional inertia set up to avert the onset of exhaustion and death.

No doubt fatigue is "a chemical affair"; toxins

or katabolites present amongst the biogens so reduce their mobility that a state of much inertia and little affectability is substituted for one where these properties are present in the opposite relationship.

Neural fatigue at the motor end-plates coming after prolonged muscular exertion sets a limit to the further volitional stimulation of muscle ; the muscle-fibres are still affectable to electric stimulation (*i.e.*, are not fully fatigued), and the brain itself is still capable of emitting volitional impulses. The functional inertia of the end-plates is the property underlying the physiological contrivance for preventing the exhaustion of the still affectable muscular substance through the still possible volitional effort.

The rhythmicality of such an organ as the heart is dependent to a very great extent upon the inertial property. The origination of a rhythm may be due to affectability, but in many cases the rhythm is maintained through functional inertia. Thus the avascular, isolated, non-fed heart "beats" for a longer or shorter time according as it has more or less of the inertial property. Mr. Morrison writing on "Tachycardia"* thus expresses himself: "the heart appears to revel in the fœtal tic-tac of emancipated visceral rhythmicality."

"Emancipated" from what ? from the heart's existing environment : this emancipation is *non*-correspondence with environment, which is, as we

* Morrison, "The Disorders of Visceral Motion." Lecture VI, *Edinburgh Medical Journal*, p. 106.

have seen, one of the results of the possession of functional inertia.

Or again, take the case of the rectum accustomed to be emptied every day at a particular hour: in many cases it will take on this diurnal periodicity and endeavour to establish its peristalsis regularly at the same hour every day—the "habit" learned through affectability is perpetrated through functional inertia.

Paget * has some very pregnant remarks on time-rates and organic periodicities. "The organic processes of repair in each tissue are adjusted to a certain time-rate which is variable according to [affectability] but is not determined by external conditions" [functional inertia]. The time-rate is implanted by the implanted properties, affectability and the inertias, and for each unit of nutrition might be reckoned a unit of time. The periodicities of organic life appear to be prominent instances of this law . . . the rhythmic movements of the heart or the motions of cilia." "In the recognition of the chronometry of organic processes, there is unquestionably great promise for the future; for it is plain that the observance of time in the motions of organic molecules is as certain and universal, if not as exact, as that in the motions of heavenly bodies. Each organic process has a definite time-rate; and each cell has its appointed period of life different for different kinds of cells.". . . "Each cell has its

* Paget, "The Chronometry of Life," Proc. Royal Institution, vol. iii. 1858–1860, pp. 117–124.

appointed period of life." These things *cannot* be due to affectability.

At my suggestion, my colleague, Mr. R. A. Robertson, looked for examples of functional inertia in vegetable protoplasm to find them as widely distributed as those of affectability. Thus, writing of plant-rhythms, Mr. Robertson says:* "The post-stimulant continuance of periodicity of growth or of movement—the opening or closing of flowers, movements of leaves—whether diurnal or seasonal is to be credited to this property of functional inertia. Thus the periodicity of growth induced by the alternation of day and night is retained for a time in continuous darkness, and seasonal periodicity is exhibited by deciduous trees when removed to countries where the vegetation is ever-green, while in cases of experimentally induced periodicity, the periodicity continues for a time after the stimuli are withdrawn. All these are examples of the katabolic phase of the inertia. For particular cases the time-value of the inertia varies: thus the diurnal periodicity is lost after two days by some plants, while it is retained for as much as two weeks by others. The latter have relatively more inertia than the former. Seasonal periodicity exhibits similar variations, and in the practical horticultural operations of forcing and cold storage, we see the property under other aspects."

The condition of latent life of plants is a notable

* R. A. Robertson, "The Functional Inertia of Plant Protoplasm," *Proc. Roy. Soc. Edin.*, Session 1901–1902, vol. xxvi. Part iii.

case of extreme insusceptibility. On this point Mr. Robertson writes:* "A more extreme case still is furnished in the winter beds of *Hydrocharis*. Terras† found that if covered up these buds could be kept in the dormant condition, that is in a condition of (anabolic) inertia for at least two years. To induce germination, heat, light and oxygen were necessary. So great was the inertia that three stimuli of a tonic character were required to elicit a manifestation of irritability, in this case growth. This example forms a transition to the condition of the dry resting seed, which may be taken as exhibiting the most extreme case of functional inertia. The *Hydrocharis* pods when dormant are not only living but are giving manifestations of life, inasmuch as they continue to respire to a slight extent throughout their dormant phase (Terras, *loc. cit.*). In the dry seed we have an organism that is living, but is affording no indication of life, inasmuch that it does not respire . . . the seed is living although not manifesting life.". . . "The dry seed may be regarded as an organism whose functional inertia is infinite for any given stimulus, but relatively small for a given combination of stimuli, viz., heat, moisture and oxygen" and light. Here "to elicit that manifestation of irritability which we call growth, and which we take as evidence of life in the seed, three tonic stimuli are necessary." "If we seek in the animal kingdom for cases to

* R. A. Robertson, "The Latent Life of Plants." *Trans. Bot. Soc. Edin.*, 1902, p. 187.

† Terras, *Trans. Bot. Soc. Edin.*, vol. xxi. 1900, p. 318.

parallel the resting seed in its condition of *vie latente* or *Scheintod*, we find them, perhaps, in the desiccated state of tardigrada and rotifera, and very likely it will be found that these organisms, when thoroughly desiccated, can withstand the same extraordinary tests as the dry seed."

The winter sleep of animals, the winter rest of plant-organs, roots, buds, &c., is due to a phasic increase of functional inertia: the rhythm of hibernation, for instance, cannot be wholly accounted for by postulating affectability alone. That hibernation does not depend on the affectability of at least the cerebral protoplasm, is shown by the fact that decerebrate frogs if kept alive long enough will proceed in due time to hibernate. Dubois, in writing on hibernation, distinctly indicates that he cannot regard it as due to the environment; the animals, he says, are "*tombés dans un état d'inertie complète.*"

Paget * cites the interesting case of migratory birds. "Among migratory birds also, it has been observed that when they are kept in confinement, and removed from all the circumstances that might be supposed to induce or necessitate their journeys, they yet become restless at the return of the season for their migration."

The organic rhythm of menstruation in the human female is an example of a typically periodic function, occurring as it does every twenty-eight days throughout reproductive life. When one considers it in the healthy woman, and remembers how the environ-

* Paget, *loc. cit.* p. 124.

ment may vary, how occupation, circumstances, mode of life, climate, &c., may all change and yet how regularly the function continues throughout life, we cannot but be struck with its independence of affectability. Of course the uterus possesses affectability; toxæmias, anæmias, and nervous discharges *will* interfere with the rhythm; and according to Darwin * there is some probability that in very early times the function was established by a cosmic process acting through affectability; but, having been so established, it is carried on—the rhythmic *status quo* is maintained—through inheritance by functional inertia in complete disregard of environmental conditions.

Change the environment as you will, take a little English girl to India, and she will begin to menstruate not at 12 or 13, the age at which the natives do, but at 14 to 17 the time appropriate to her own race. This is the kind of phenomenon that is due to functional inertia. The very fact that the function has its own time of life to appear, continue and disappear independently of external and of many internal conditions, is sufficient of itself to reveal the inertial character.

It is more particularly in connection with the generative organs that we find rhythm playing a conspicuous part: no doubt these organs possess affectability, are accessible to stimuli, but they as certainly possess a property of independence of environment and of spontaneous phasic activity.

* Darwin, "Descent of Man," p. 254. (Murray, 1901.)

The rhythm is most noticeable in the activity of the female reproductive organs; but, as several writers have observed, rhythm is by no means absent from male organs and organisms. Havelock Ellis* goes so far as to write, "There is some reason to believe that *men* do actually pass through a rudimentary menstrual cycle affecting the whole organism."

But as long ago as 1815, Spurzheim † said the same thing. Phrenologist though he was, all he wrote was not valueless.

Speaking of periodic fits of irritability he wrote (p. 560), "They affect all persons, men and women, at least once within twenty-eight days, weak and irritable persons feel their influence twice within the same time."

It is well known that in the case of the female the phasic activity is not by any means confined to the pelvic organs. As I wrote in 1902:‡ "The phenomenon of menstruation is undoubtedly the expression of a functional monthly rhythm involving not merely the uterus and other pelvic organs but in a less marked manner the whole female organism. The systemic symptoms, headache, lumbar pains, cardiac palpitation, congestion of thyroid and mammæ, loss of clearness of complexion, tendency to pigmentation, malaise, being easily tired, depression of spirits, impairment of voice, and certain

* Havelock Ellis, "Man and Woman," p. 245. (London, 1894.)

† J. G. Spurzheim, "The Physiognomical System of Doctors Gall and Spurzheim." (Edinburgh: Blackwood, 1815.)

‡ D. F. Harris, "Periodicity of Hemicrania in the Male," *Edinburgh Medical Journal*, July 1902.

other emotional and intellectual alterations are only partly explained by reflex irritation from the hyperæmic internal genitalia." That is to say, affectability alone will not give a full account of this general phasic disturbance—we need not search in the environment for "sufficient causes" of it. The pulse in respect of fulness and rate undergoes a monthly rhythm (Cullen), the blood-pressure is at a maximum from one to seven days before the onset of the discharge (Jacobi), and falls to a minimum two days after its cessation, the monthly temperature curve is highest a few days before the illness, and during the flow the urea is diminished and the uric acid increased (Haig). All this is expressed by saying that there is in the female a great metabolic 28-day rhythm, a waxing and a waning alternately in the intensity of the tissue-changes; the meaning and purpose of which does not at present concern us. Is there anything analogous in the male metabolism?

Dr. Harry Campbell * in his suggestive work has a chapter entitled: "Is the menstrual rhythm peculiar to the female sex?" and he answers it in the negative. He quotes cases in the male of periodic bleedings from ulcers, hæmorrhoids and kidney (recurrent hæmaturia), and endeavours from the rhythmicality observed in attacks of hemicrania in the male to corroborate his negative. Now the periodicity of this last-mentioned ailment is the most peculiar thing about it. Professor Osler,†

* Harry Campbell, "Differences in the Nervous Organisation of Man and Woman." (London: Lewis, 1891.)

† Osler, "Text-book of Medicine," p. 1011. (Pentland, 1895.)

writing of hemicrania, says: "The attacks may occur on the same day every week, every fortnight or every month," and Dr. Mackenzie* says of it, "One of the most peculiar features of these cases is the periodicity of the attacks. Many patients know when an attack is due, although there may be no premonitory symptoms." There is then here a weekly, bi-monthly or monthly rhythm—a rhythm independent of the environment—something due to the functional inertia of the organism as a whole. In 1902 I published an analysis of certain records of hemicranial headache kept for three years by the patient himself, and from these I fully demonstrated the rhythmic character of the morbid metabolism here involved. After noting the precise periodicity—mostly bi-monthly—I remarked, "These results are sufficiently striking when we remember what a degree of constancy of phasic metabolic condition this indicates amidst the greatly altering environmental conditions extending over three years." We have but to glance at the changing occupations of the professional man in question—his ordinary work during the day, with dining at home, or dining out in the evening, attending public dinners or entertainments, breathing good air and bad, making speeches or listening to them, travelling by land or sea, having meals at irregular hours and meals varying in quality and quantity, having hours of sleep curtailed, &c.—in order to see that the environment frequently altered without any corresponding alteration in the

* In Clifford Allbutt's "System of Medicine."

metabolic rhythm. The stimuli changed quantitatively and qualitatively, but the metabolism held on its own perverted way, expressed itself in its own unrelated independent periodicity—this is functional inertia.

Peculiarities of behaviour, whether in cells or in individuals, are not brought out until some small thing goes wrong—the slight departure from the normal metabolism (probably of purins) is sufficient to bring out in these cases the presence of a deep-seated rhythm. "Life is characteristically rhythmic," says Vaschide.*

The cases of established habits liable to become perpetuated by functional inertia are very numerous: one example may be given: nurses who have been on night-duty on being changed to day-duty, often have sleeplessness,† *i.e.*, nocturnal wakefulness has become a habit and is maintained under inappropriate circumstances. Professor Gaule, for instance, holds that muscle is subject to periodic variations in its rate of growth.‡

In his exceedingly interesting analysis of the central nervous system, Dr. Mercier,§ ever and anon, uses the concept, and sometimes, as we shall see, the term "inertia": writing of excessive katabolic effects in nerve-cells, he says, "This decomposition (katabolism) is in normal organisms prevented by the

* Vaschide, *Comp. Rend.*, vol. cxxxv. 1902, pp. 752–754.

† Bradbury, Allbutt's "System of Medicine," vol. vii. p. 748.

‡ Gaule, *Nature*, vol. lii. 1895, p. 555.

§ Mercier, "Sanity and Insanity," Contemp. Science Series, p. 182.

inherent stability of their tissue, from occurring in excess." What is here called "inherent stability" sets a limit to affectability: evidently Dr. Mercier's "stability" is what I have named inertia. Elsewhere (p. 304) Dr. Mercier writes: "the molecules fall back into their old positions"—the idea of inertia is latent here.

APPENDIX

Professor Bose in his book on "Plant Response," published in 1905, analyses in a very interesting way the factors which are causal in the production of rhythm. On page 311* we read: "We have thus obtained some insight into that very obscure phenomenon which is known as the after-effect. By the inertia of the organism there is a certain loss of time before response begins to take place, and this determines the latent period. But when the stimulus has already initiated movement, the responding organ will, through the same inertia, continue to show this movement even when the stimulus has ceased to act."

It is satisfactory to me to find so able a biologist as Professor Bose adopting my views and almost my own words on "inertia of the organism," a synonym for functional inertia, even although according to him

* "Plant Response as a Means of Physiological Investigation," 1905.

this "inertia" will not account in its entirety for protoplasmic rhythm.

Professor Bose gives a physical model * to help us to visualise the process underlying rhythmicity —in particular the rhythm that occurs after the application of a *constant* stimulus. A cistern fed by a constant inflow has an india-rubber outflow pipe constricted near its orifice by a "compressing spring." Water flowing out of the flexible tube encounters resistance at the constriction, and when the internal pressure rises to a certain magnitude it overcomes the spring and makes the water jerk out: this outflow lowers the internal pressure, the spring comes down again on the tube and the outflow is once more diminished. This alternate diminution and increase of the volume of outflow is of course rhythmical.

Accepting the illustration as sufficient, it is evident that the behaviour of the spring gives us the explanation of the conversion of the steady into the rhythmic flow. By the increasing internal pressure the spring is, after a time, overcome and forced up, and this period, Professor Bose admits, "corresponds to the latent period in plant-response" —but the spring *returns* to the tube, *i.e.*, returns "of itself," *i.e.*, automatically.

By the possession of what properties of matter does it do so?—by its elasticity and inertia. We have accounted for a rhythmic outflow (under constant

* "Plant Response as a Means of Physiological Investigation," 1905, p. 310.

inflow) by referring back the possession of automaticity to one of the causal factors—a spring which has both the inertias—that of rest (which accounts for the "latent period") and that of movement which along with elasticity "accounts" for its automaticity.

Professor Bose says, "On account of the oscillating mechanism, the outflow . . . (is) periodic." The oscillating mechanism oscillates because for one thing it has elasticity—a property of matter intimately related to molecular inertia.

The "oscillating mechanism" of the physical model is the phasically altering metabolism of the biogens of the living protoplasm: the oscillating mechanism in the one case has physical inertia, the molecules of the protoplasm in their alternating phases of metabolism have functional inertia.

While thus analysing Professor Bose's illustration, I by no means intend to undervalue what he says as to the factor of absorption of energy, and the holding of it latent which is, undoubtedly, of very great importance as a factor in rhythmicality—a factor related rather to affectability and therefore not at present under review.

CHAPTER III

FUNCTIONAL INERTIA EXHIBITED AS POST-STIMULANT AND POST-MORTEM ACTIVITY

In the last chapter I reviewed evidence showing that the possession of inertia on the part of protoplasm was variously manifested by latent periods, refractory periods, insusceptibilities of all kinds, and the establishment of limits to the amount and potential of activity—phenomena capable of being grouped under inertia of rest, anabolic inertia; we now pass on to a group of phenomena complementary to these. The push has been given, the inertia of rest overcome, and now, if the stimulus—push—be stopped, the great door continues swinging on through a certain angle—action outliving stimulus. Biologically, post-stimulant action is the counterpart of this swing after ceasing to push.

Post-stimulant activity is due to katabolic inertia. A case of this is illustrated by Ehrlich's theory * of the overproduction of free receptors so as to give rise to antitoxin in the blood of the immunised animal. The presence of the toxin in the blood of a susceptible animal stimulates the tissue-cells, which,

* Hill and Co-writers, "Recent Advances in Physiology and Bio-chemistry," p. 443. (Arnold, 1906.)

possessing affectability towards this stimulus, respond or react by detaching certain "side-chains" which as antitoxin neutralise the toxin introduced. But if this were all, there would be no acquired immunity from future infection. Ehrlich at this point assumes an *over*production of free side-chains or receptors as antitoxin; but this is a post-stimulant production, it is a production in excess of immediate needs, it is a response that has outlived the stimulus, it is an expression of katabolic inertia. Obviously the *in*-susceptible animal has maximal protoplasmic inertia towards the toxin. Weigert believes that this over-production is characteristic of all tissue-repair, if so, it is dependent on katabolic inertia. Macleod,* writing on the production of endogenous purins, remarks, "Purin increase due to muscular activity existed not only during the actual working time, but for some time after it"—post-stimulant activity.

Functional inertia expresses itself in what must be thought, by the non-biologically minded, a most paradoxical fashion—post-mortem vitality. The death of an animal as a whole by no means involves there and then the death of all its various constituent tissues. In the case of unicellular organisms portions will live separated from the main body; the non-nucleated portion of the bisected Lacrymaria olor for a certain time lives and moves although, possessing no nucleus, it cannot ultimately survive; the non-nucleated pseudopodia detached

* Hill and Co-writers, "Recent Advances in Physiology and Bio-chemistry," p. 431. (Arnold, 1906.)

from Difflugia * for a time secrete lime, but ultimately die, and even an isolated nucleus does not instantly die : it cannot assimilate, however, in the absence of cytoplasm.

(The nucleus is more resistant towards phagocytic absorption than is the cytoplasm.)

We all know that, *e.g.*, the cilia are active or many hours after death if kept from drying : in the trachea of man Virchow † found them living 38 to 48 hours post-mortem : the cilium therefore must be regarded as the "ultimum moriens." Valentin says it can live three days p.m. hominis. Ciliary action is notably rhythmic, 10 to 20 times a second (maximum) ; it is notoriously independent of nervous control, even the co-ordination of the movements not being carried out by the nervous system ; it has a period of latency after stimulation, as we have seen, and it has a long period of post-mortem activity, so that it possesses in a high degree the property of functional inertia.

Mitotic changes are known to occur in the nuclei of cells of the human cadaver. The sphincter iridis lives for five hours post-mortem. The epidermis lives for a day or two after "somatic" death, and hairs and nails as epidermal products can still grow. The bronchial muscles are alive half an hour after somatic death. According to Halliburton and Mott, nerves isolated from their trophic cells retain their conductivity for some days. There is no question

* Verworn, "General Physiology," p. 513. (Macmillan.)

† Virchow, "Cellular Pathology," p. 293. (London : Churchill.)

as to the reality of post-mortem production of heat * —an outward expression of katabolic inertia. The uterus, it is well known can, after the death of the mother, contract on the fœtus and expel it, so that a living child can be born of a woman dead in the eyes of the law.

As chemically expressed, this post-mortem katabolism is seen in the many tissues (notably liver and kidney) that can reduce alizarine blue to alizarine white,† and soluble Prussian blue to the green or leuco condition,‡ and also in all those cases of surviving activity of isolated organs or tissues performing chemical transformations in the absence of nutrient fluids—tissues excreting CO_2 into an atmosphere of N or H. Similarly, the frog in Pflüger's experiment in which blood had been replaced by physiological salt solution, and the avascular non-fed muscle excreting in vitro CO_2 into N or H, have katabo ic inertia.

So, too, glands of various kinds which continue post-mortem in the absence of all stimulation to secrete, are exhibiting katabolic inertia.

A typical case of this is the avascular liver continuing post-mortem to manufacture the (glycolytic) ferment for the transformation of glycogen to dextrose. Tissue-autolysis is due entirely to katabolic inertia.

* Tigerstedt, "Text-book of Human Physiology." (London: Appleton, 1906.)

† Paul Ehrlich, *Das Sauerstoff-Bedürfniss des Organismus.* (Berlin: Hirschwald, 1885.)

‡ D. F. Harris and J. C. Irvine, *Biochemical Journal*, Sept. 1906, and D. F. Harris, *Science Progress*, April 1907.

With regard to muscles, Lagrange * points out that muscles which have, for many years, been in a state of "training" remain in the *status quo* although the strict life has been given up.

With respect to the katabolic inertia of entire organisms, Gamble † tells us, *e.g.*, that certain prawns change their colour to a blue during the night; if however they be kept in continuous light for a sufficiently long time, they continue to change their colour at their normal rhythm independently of darkness altogether.

Examples of post-stimulant activity in vegetable protoplasm appear to be very numerous according to Mr. R. A. Robertson ‡ who thus writes: "Passing on to consider the functional inertia of excised and isolated organs, we again find no lack of examples in consequence of the lower pitch of vitality and greater individuality of plant protoplasts. As the wheel continues in virtue of its inertia of motion to rotate, it may be for a considerable time after the driving-gear is slipped, so many plant organs and cell organoids continue to function for a time when isolated. This is a manifestation of their katabolic inertia. Isolated chloroplasts, for example, assimilate for five hours, isolated endosperm of Ricinus lives and carries on metabolic change for six months." . . . "Isolated scutellar

* Lagrange, "Physiology of Bodily Exercise," p. 221.

† Gamble, *Nature*, vol. lxii. Oct. 11, 1900, p. 590.

‡ R. A. Robertson, "Latent Life of Plants," *Trans. Bot. Soc. Edin.*, Session lxvi. 1902, p. 184.

epithelium secretes enzymes and corrodes starch-grains. Isolated fragments of swarm-spores move, and of cytoplasm stream, while Demoor found that nuclei continued their mitosis after the protoplasm was killed by CO_2 or chloroform.

"Again, isolated leaves of *Drosera* continue active, translocation takes place in heads of cereals, and ripening in fruits after separation from their parent plant, and oak-galls continue their internal metabolic changes when removed from the tree." *

Gautier has made a study of post-mortem life as embodied in his paper, "Sur les produits de le vie residuelle des tissus en particulier du tissu musculaire séparé de l'etre vivant." †

Post-stimulant activity is well seen in the case of the heart stimulated through its accelerator or augmentor nerves. After a latent period (anabolic inertia) its rhythm is accelerated (affectability), and when this has been going on for some time, if the stimulus be suddenly cut off, the heart continues to beat at the higher rhythm for some time, thirty seconds in frog-heart: this post-stimulant period is due to katabolic inertia.

But a post-stimulant effect—an after-effect—may of course also be one of no action, provided the effect of stimulation has been inhibition or arrest of function.

In the heart of the cold-blooded frog or tortoise this is very well seen: an inhibitory stimulus is

* Macdougall, "Vegetable Physiology," p. 64.

† Gautier and L. Landi, *Comp. Rend.*, vol. cxiv. 1892, p. 1312.

turned on to the beating heart, and it continues to beat for a short interval (katabolic inertia) before its affectability is displayed, when it becomes inhibited (response), then, on cessation of the inhibitory stimulation, it remains in its state of quiescence or predominant anabolism (Gaskell)—in the *status quo* in fact for a certain time; this is the period of anabolic inertia.

In connection with cardiac inertia I cannot do better than quote Professor Gregor Brodie * dealing with cardiac refractory period and the inability to tetanise the heart. "We note the most striking result that no second contraction is produced. It has fallen on the muscle fibre during a time when it is *unable to respond* to a stimulus . . . termed its refractory period." "A heart cannot be sent into complete tetanus . . . as tetanisation proceeded the refractory period tended to increase. Note, moreover, that a contraction occurred *after* stimulation had ceased, showing that the effect of the stimuli did not stop immediately stimulation ceased."

In these sentences we have both the anabolic and katabolic inertia of cardiac muscle described.

Again it is in virtue of the katabolic inertia of non-striated muscle that there elapses the relatively very long latent period of 18″ before stimulation of the splanchnic nerve is followed by inhibition of the intestinal movements, *i.e.*, induces the anabolic phase.

* T. G. Brodie, "Essentials of Experimental Physiology," pp. 110, 111. (Longmans, 1898.)

Post-stimulant phenomena are very numerous in connection with the central nervous system, both in cells related to and those not related to consciousness. The former activities will be dealt with in the chapter on psychic inertia. Several writers on Neurology recognise the latter, Dr. Mercier,* for instance, writing of the metabolism of cells of the nervous system, says: "Activities will not suddenly cease;" this is functional inertia, and it is the post-stimulant expression of it: again the same author writes of "some property analogous to *momentum*," † *i.e.*, katabolic inertia: but the anabolic phase is equally before Dr. Mercier, for early in his suggestive work he uses the expression, "the resistance which the *inertia* of the lower centres opposes to the disturbance of their equilibrium" ‡—all these uses of the term I saw after I had published my views.

* Mercier, "Sanity and Insanity." Contemp. Science Series, p. 270. (Walter Scott, 1890.)

† *Ibid.* p. 183. ‡ *Ibid.* p. 27.

CHAPTER IV

FUNCTIONAL INERTIA AS RELATED TO HEREDITY

JUST as there is no property in the organ which is not to be found in its component cells, and nothing in the organism which is not in its component organs, so there is nothing in the race which is not in its component units, individuals. Functional inertia is expressed racially because it has existed individually, and is expressed in the individual because it is a property of the living units—the cells—of which the individual is built up. We have seen that functional inertia is a fundamental property of the simplest portion of undifferentiated protoplasm, we shall see that it is no less responsible for racial characteristics and national destinies. An organism in action is, at any one instant, what it is in virtue of two distinct tendencies—the tendency to correspond with the environment, to profit by education, a tendency obviously the outcome of affectability, and the opposite tendency—to disregard the environment, not to be educable, to maintain the ancestral *status quo* transmitted and unmodified, this is evidently related to functional inertia. All one's endowments are the result either

of inheritance or of acquisition. By environmental stimuli acting through affectability we become educated, trained to be what, under other circumstances or in another environment we might not ever have become, whereas through the possession of functional inertia, character is inherited and certain tendencies are innate, and one's individuality unfolds as the underlying ground-tone of the life, and we are what we could not in any way whatever help becoming. By an internal momentum, character, " the person," is forced into manifestation, in opposition it may be to parental objections, the teacher's frown and the disapproval of society generally. There is an inertia of character in the family, the clan, the nation, the race. It was not affectability in the family that was alluded to when the Bourbons were described as the dynasty " that had learned nothing and forgotten nothing." Place the Jew, for instance, anywhere under the soft southern sky or the harsh grey north, and he never alters, he is the same physically and mentally as he was a few thousand years ago: neither time nor environment can change him. Professor Haeckel is evidently referring to this twofold tendency in living beings when his views are represented by Professor Huxley * as follows: " Professor Haeckel looks upon the causes which have led to the present diversity of living nature as twofold. Living matter he tells us is urged by two

* T. H. Huxley, " Darwiniana : Collected Essays," vol. ii. p. 114. (Macmillan.)

impulses, a centripetal which tends to preserve and transmit the specific form and which he identifies with heredity, and a centrifugal which results from the tendency of external conditions to modify the organism and effect its adaptation to themselves. The internal impulse is conservative and tends to the preservation of specific or individual form, the external impulse is metamorphic and tends to the modification of specific individual form." Professor Haeckel comes within a very little of speaking of inertia and affectability in this passage—undoubtedly what I mean by the former he designates the "internal impulse" with its conservative tendency tending to preserve, while the latter is, of course, only another name for that which underlies the modifiability of the organism. Haeckel does, as I do, identify the internal conservative tendency with heredity. I may say that I first read the above passage, four years after I had published my first paper. Naturally I was confirmed in my manner of viewing the properties of protoplasm when I found that I had the unconscious support of one of the greatest of living biologists. Haeckel clearly recognises the antithesis between environment related to affectability on the one hand, and the internal impulse to preserve the inherited *status quo* on the other: on this latter the environment is powerless. If one property, affectability, underlies the tendency to correspond with environment, it is impossible that the same property can simultaneously underlie an entirely opposite tendency,

viz., to disregard the environment. There must be *two* properties correlated of course, but physiologically opposite if not antagonistic. Now Haeckel as clearly as possible regards life, as I do, as the *resultant* of the simultaneous possession of the two complementary tendencies. Once we have assumed the existence of this other fundamental property in protoplasm, a very great deal of the phenomena of heredity and reproduction is explicable.

Huxley speaks of "the *inevitable* recurrence to the original type:" * why inevitable? Because inertial; it is as "inevitable" as that because of momentum the pushed door should swing on, the disturbed rocking-stone oscillate, the express train dash through the obstructions. Functional inertia preserves race-peculiarities, preserves constancy of type through very long periods of time. As Professor Huxley has well said,† "Any admissible hypothesis of progressive modification must be compatible with persistence without progression through indefinite periods." Thus the type of certain fishes has been preserved for ages from very early geological times. "No order of fishes is known to be extinct," says Professor Huxley.‡ According to Professor Ewart the type of "the horse with the Roman nose" is another

* T. H. Huxley, "Darwiniana: Collected Essays," vol. ii. p. 114. (Macmillan.)

† *Ibid.* vol. viii. 1902, p. 304.

‡ *Loc. cit.* p. 354.

case of age-long type preservation. Again Huxley * may be quoted as follows: "The tendency to reproduce the original stock has, as it were, its limits, and side by side with it there is a tendency to vary in certain directions, as if there were two opposing forces working upon the organic being, one tending to take it in a straight line, and the other tending to make it diverge from that straight line, first to the one side and then to the other." Now could we have the notion of functional inertia better expressed short of using the term itself? It is by its inertia of mass in movement that a body *tends* to travel with uniform motion in a straight line, and similarly it is in virtue of the functional inertia, as a property of living matter, that the organism tends in Huxley's phrase to "go in a straight line."

The two tendencies thus rule the protoplasm—the tendency to maintain the *status quo* and the tendency to vary, to respond to, *i.e.*, to correspond with environment—the centripetal and centrifugal impulses of Haeckel are functional inertia and affectability. Not that necessarily every so-called "variation" is the result of environment acting on affectability; under certain conditions the atavistic tendency may bring to light some feature which, with imperfect knowledge of the organism's phylogeny, we might think to be a variation in the sense of something new, whereas what has become noticeable for the first time to the observer may

* T. H. Huxley, "Darwiniana: Collected Essays," vol. ii. 1902, p. 398.

really be only some feature latent for a long time in the past history of the organism, something *not new*, in short, but ancestrally possessed. A variation arising through the genuine influence of the environment on affectability may be perpetuated through functional inertia, as Huxley says:* "The variation in the plant once fairly started tends to become hereditary and reproduce itself." Just as functional inertia may oppose the appearance of a reaction (hence the phrase "once fairly started"), so functional momentum will tend to perpetuate it, even, it may be, in the face of disadvantageous surroundings. "It has been shown," says Professor Huxley, "that certain forms persist with very little change from the oldest to the newest fossiliferous formations, and thus show that progressive development is a contingent and not a necessary result of the nature of living matter." It depends on the relative degrees of intensity of possession of affectability and functional inertia whether "development" is fostered or the *status quo* maintained. Spencer † speaks of "a proclivity towards structural arrangement of species"; this is inertial. Huxley ‡ puts the same idea in several ways in his collected essays; Darwinism "is perfectly consistent with indefinite persistence in one state," and again,§ Nature "always tending to repeat or to return to the primitive type," and

* T. H. Huxley, "Darwiniana: Collected Essays," vol. ii. 1902, p. 440.
† Spencer, "Wood's Holl Lectures," 1894, p. 29.
‡ "Collected Essays," vol. ii. p. 90. § *Ibid.* p. 397.

again,* "Atavism—one of the most marked and striking tendencies of organic beings; this hereditary tendency," and again† "the tendency of races to return to their primitive type." Functional inertia, as racially expressed, is responsible for keeping nations unprogressive, backward as regards civilisation according to our ideas; it can scarcely be affectability that has done it. Viewed thus, the Chinese, who are to-day, as regards their enlightenment, almost exactly where they were a few thousand years ago, have much functional inertia; we know how excessively conservative they are, and what enormous obstacles Western ideas encounter amongst them. This is so obviously inertial, that a recent writer, M. Guyau ‡ uses the very term with reference to a similar race, the Turks—"The Turk with his Oriental Inertia."

Environment acting through affectability has certainly produced and established racial characteristics—the solemn man of the cold Northern hills, the light-hearted vagabond of sunny Sicily—but functional inertia, having preserved the *status quo*, is responsible for their being maintained under, it may be, very different conditions. The Irishman or the Aberdonian, encountered at the Antipodes, is found to have retained his brogue and his humour, his accent and his caution respectively: certainly

* "Darwiniana: Collected Essays," vol. ii. p. 398.

† *Ibid.* p. 425.

‡ J. M. Guyau, "Education and Heredity," Contemp. Science Series, p. 67. (London: Scott, 1891.)

America or Australia may make him somewhat different from the man he was before he set foot on their shores, but never altogether different. The Leopard still cannot "change his spots nor the Ethiopian his skin." By the same property of inertia are preserved various vestigial organs—pineal body, appendix vermiformis, membrana nictitans which may be of no use to the possesor and are sometimes positively harmful; the ease with which the appendix becomes the seat of disease is quite notorious. But by a "blind persistency" they are preserved by functional inertia. By the same property of protoplasm certain evanescent organs are caused to appear in the embryo of each succeeding generation,—branchial clefts, coccygeal vertebræ and other anatomical details so familiar to the embryologist. Some are wholly evanescent—the branchial clefts, others not; but every now and again even the mammal exhibits an avian relic, as was the case with a puppy bull-dog born a year or two ago at Shotton, in Flintshire, which had a perfect wing instead of one foreleg. Occasionally, by a still greater display of functional inertia, the fœtal type is carried right on into the adult period; thus the "dog-faced man" of public shows is a case of *Hypertrichosis universalis vel Lanuginosa fœtalis.* Functional inertia is the mechanism of heredity. The property of protoplasmic inertia in fœtal tissues has been appealed to by Professor Adami,* to explain such fœtal inclusions as Syncytioma malignum.

* J. G. Adami, *The Clinical Journal,* June 18, 1902.

It is the nature of the fœtal villi to burrow their way through maternal tissues, but when, through their functional inertia, they continue to perform this burrowing after their growth should have ceased they give rise to a malignant epithelioma. Malignancy is thus related to protoplasmic inertia. Professor Adami, both in his paper on "The Causation of Cancerous Growths" * and in a private communication to me, acknowledges that what he had, since 1896, called "habit of growth" in certain cells which ought not to be proliferating then or there, is "based upon that principle of inertia" concerning which he quotes from my first paper and which he had first seen formally treated there. A remark of Sir Lauder Brunton's is explicable in the light of these considerations, "not disease itself, but the tendency to it, is hereditary." † The tendency as a molecular pre-adjustment in one generation is by functional inertia carried over into the next generation; the acquirement of the disease is the result of a specific stimulus (the pathogenic micro-organism) acting on the individual affectability (susceptibility) towards the "infection."

In connection with heredity we have the very important subject of reversion to type—of type-stability, on which such a writer as Mr. Francis Galton has a good deal to say. He thus expresses himself, "Regression towards mediocrity in hered-

* Adami, *British Medical Journal*, March 16, 1901, pp. 624–626.

† Brunton, "Croonian" Lecture."

itary stature;" * and again, "in a complete theory of heredity the stability of an organism has to be regarded."† And once more, "the factor of stability of type has to be reckoned with."‡ Now it is worse than useless to attribute this stability of type to affectability—it is subversive of the most elementary ideas both in biology and etymology. Reversion to a type and the stability of a type, are alike the result of the possession of functional inertia by the species—a property resident in the protoplasm of each member of the group. The "fatality" of functional inertia as expressed in reversion—atavism—is so well described by Dr. Mercier that I cannot refrain from quoting a passage in which, after alluding to atavism in animals, he writes,§ "The tendency for the developing organism to unfold after one particular manner and in conformity with one general type has been fixed by transmission through so many generations, has acquired such force of *momentum* in its long descent, that the local and perhaps temporary influences which produced in the parent a deviation from the type are over-borne in the offspring by the steady enduring massive pressure of its race-heredity." A little later the parallel case of the plant is described: "Thus when a gardener has, with utmost pains and skill, produced a new variety of plant-form, he is often exasperated to find that in spite of all his

* Francis Galton, "Natural Inheritance," p. 31. (London: Macmillan, 1889.) † *Ibid.* p. 193. ‡ *Ibid.* p. 196.

§ Mercier, "Sanity and Insanity," p. 151.

exertions, a large proportion, the majority, it may be the whole of his seedlings, will revert to the original form." "The accumulated *momentum* of the developmental forces . . . bears down all opposition to their progress in the wonted direction." Here the very term *momentum* is used—and momentum is inertia of mass in motion. We have merely not to read into this passage the notion that these things are only analogies, but, to arrive at the truth, have just to admit that they are due to the property of functional inertia in the protoplasm of living beings—whether animal or vegetable. "Reversion," says Professor Ribot,* "to the physical or mental type is therefore the result of natural laws, and by no means of a mysterious or occult influence." Here functional inertia is expressed as an insusceptibility towards all conditions tending to make the type alter, the "conservative tendency," the "fatal force" of philosophical embryologists. "The fatal force of the law of regression to the race type" is the expression used by H. F. Osborn.†

Now the force of a law must operate upon some property; laws, forceful or otherwise, convey no properties or powers for action. In the same strain writes E. G. Gardiner,‡ "It is thus evident that the plasm is very conservative and difficult to

* Ribot, "Heredity," p. 380. (London: H. S. King and Co., 1875.)

† H. F. Osborn, "Evolution and Heredity," "Wood's Holl Lectures," 1890.

‡ E. G. Gardiner, "On the Origin of Death," *Ibid.* p. 116.

change, that the conservative forces far outweigh all tendencies to vary." Without using the term, it seems to me very evident that what these authors are describing is functional inertia in the species—the inherent something, the conservative something that is oblivious of environment, that holds on the even tenor of its way, the tendency not to change though all else changes; this is functional inertia, the stability, the insusceptibility, the "fatal" reverter. This is "the something that stands over against variability" in the mind of Mr. Gardiner,* who again expresses himself thus: "Variation, then, is a consequence of the union of two sexual germ-plasms, and not something inherent in the protoplasm"—the something that is "inherent" in the protoplasm is the inertial property. Mr. Spencer† uses the term "mechanism of inheritance," and asserts it must be the one through which metabolism operates. One aspect of metabolism—the inertial—is more particularly related to it, the functional mechanism whereby is maintained the *status quo* as inherited of family, species, order or race. The botanists, in particular, are impressed with reversion to and stability of type, phenomena of plants which need not surprise us when we recollect how largely anabolic is the inertia of vegetables. De Varigny, in his "Experimental Evolution," makes prominent this aspect of his

* E. G. Gardiner, "On the Origin of Death," "Wood's Holl Lectures," 1890, p. 116.

† Spencer, "Wood's Holl Lectures," 1904, p. 29.

subject. He confesses * how very difficult it is to perpetuate progress, difficult to maintain any natural or artificial race at its highest standard; degeneracy interferes with and ruins the work of man and of nature—in other words, functional inertia swamps affectability. "Many horticulturists complain that all variegated plants when grown on their own grounds soon *revert* to the ordinary type. There is an unknown influence at work in those cases." Unless protoplasmic inertia be postulated, it is an unknown influence; henceforth it need not be unknown. Again, we read,† "The Italian hemp planted in France rapidly ‡ reverts to the small variety;" and once more,§ "There is a limit set both to the increase and to the decrease in size of a plant. You cannot force it to become much larger than its type, nor can you dwarf it below a certain limit"—these limits are set by vegetable functional inertia. This same property of course is responsible for maintaining the specific character of a graft implanted on a foreign stem. An interesting topic is touched upon when De Varigny says: "The species seems for a long time to *resist* all inducements to variation, when all of a sudden it begins to vary considerably." Into this side-issue we must not be tempted to digress. Vegetable protoplasm, it appears, can exhibit "polarity" which may be regarded as an "after-

* De Varigny, "Experimental Evolution," Nature Series, pp. 75, 76. (London: Macmillan, 1892.)

† *Ibid.* p. 72. ‡ In two or three years. § *Ibid.* p. 76.

effect phenomenon induced by gravitation and stretching beyond the life of the individual as a phenomenon of inherent or stable induction and therefore an inheritable disposition." * After quoting this passage Mr. Robertson † continues, "For the more or less indelible impression of this character by summation of effects the property of inertia would be a necessary preliminary. On account of their greater functional inertia, polarity is more indelibly stamped on some plants than on others, and in the latter in consequence of their smaller degree of inertia, it is possible to alter the polarity by the influence of external conditions. It would seem that in the acquirement of characters generally by living matter, *i.e.*, in education of protoplasm, functional inertia is a factor of great importance." Protoplasmic inertia, then, is responsible for hereditary transmission, either of morphological, physiological, or, as we shall see, psychical features, *i.e.*, the offspring is, to a large extent, maintaining, *i.e.*, reproducing, the parental *status quo*. In this connection we have to notice these cases of "preformed adaptation" of which Weissmann‡ says, "External conditions have only served to bring some preformed adaptation into activity." That is to say, in the individual exhibiting them, preformed adaptations are not causally dependent on the en-

* Detmer, "Physiology," p. 507.

† R. A. Robertson, "Latent Life of Plants," *Trans. Bot. Soc. Edin.*, 1902.

‡ Weissmann, "Romanes Lecture," 1894, *Nature*, vol. l. p. 31.

vironment, whatever they may have been in a much earlier period of ancestral history. Having been evolved as adaptations related to affectability, functional inertia of protoplasm perpetuates them by making them to be inherited. The moment a chick is hatched it picks up seed, the first time a kitten sees a dog it is afraid,* the young bird shows signs of fear the moment it sees the hawk, but shrinks from no other bird,† the moment the child's lips touch the nipple the movements of sucking begin. This is hereditary, preadjusted disposition—it is inertial. No doubt it is by affectability that the reflex actions appropriate to these various acts occur, but the carrying over of the particular molecular preadjustments from the previous generation —the transmitting intact the adaptation—that is inertial, it is the maintenance of a *status quo ante*. One very striking instance of what I mean was lately described to me by a Fifeshire gentleman who is a very close observer of bees. He had been carrying in a box from the hives up to his house two unhatched "queen-bees," each in her cell; and on arrival indoors, opened the box to find one of the queens in the act of being hatched; thirty seconds after, the second queen was hatched. Instantly, and as it were without warning or premeditation, the elder by thirty seconds, flew on the younger sister and stung her to death through the thorax.

* De Varigny, *loc. cit.* p. 225.

† Lloyd Morgan, "Animal Behaviour," p. 49. (London: Arnold, 1900.)

This was an almost instantaneous unfolding of functional propensities certainly not in virtue of training or of education, or of the environment, but in virtue of a preadjusted capacity—it was due to functional inertia.

Throughout Dr. Mercier's work the stability and instability of the nervous system are contrasted. The stable nervous systems are those with much anabolic inertia and little affectability, in the unstable these are reversed. Dr. Mercier after alluding to what the environment can effect on a plastic (affectable) nervous system says,* "the fact remains that for the great majority of people the question of the stability or instability of their highest nervous arrangements resolves itself into a question of the kind and degree of organisation that they have inherited from their ancestry." We have seen that the property underlying the mechanism of inheritance is the inertial one—it maintains the *status quo*, stable if stable, unstable if unstable. We have seen how Dr. Mercier employs the notion of momentum, he finds it indispensable—"an organism by its possession of what for want of a better term *I must call*† momentum."‡ I would only add tha there is no better term, for the good reason that it is a term related to a property in protoplasm—katabolic inertia—which we must reckon with in our analysis of organic existences whether normal (sane) or abnormal (insane).

* "Sanity and Insanity," p. 143.

† The italics are mine.

‡ "Sanity and Insanity," p. 182.

As in the case of plants, so in animals, we have many instances of the difficulty and impossibility of overcoming the inherited by means of the acquired. Speaking of his own inherited left-handedness, the late Sir Daniel Wilson said,* "Nor has the habit (of using the right hand) fostered by the practice of upwards of seventy years overcome the preferential use of the other hand." The inherited *status quo* is based on too primitive a property—inertia—to be overcome even in a long lifetime. Most truly might the late Sir Michael Foster write,† "What we are is in part only of our own making, the greater part of ourselves has come down to us from the past." This aspect of things had impressed the late Professor Tyndall. In his address to students at University College,‡ he said, "We may remove obstacles and render latent capacities active, but we cannot suddenly change the nature of man. No man knows what the potentialities of any human mind may be, requiring only release to be brought into action. There are in the mineral world certain crystals which have lain darkly in the earth for ages, which nevertheless have a potency for light locked up within them. In their case the potential has never become actual. The light is, in fact, held back by a *molecular detent*." The italics are mine, for Professor Tyndall meant

* Daniel Wilson, "Left-handedness," p. 142. (Macmillan, 1891.)

† Foster, "History of Physiology," p. 1. (Cambridge University Press, 1901.)

‡ Tyndall, "Fragments of Science," vol. ii. p. 97. (Longmans, 1902.)

here what some have called molecular friction and others molecular inertia. In the famous Belfast address,* he said (amongst other things that proved more controversial), "These *pre-determined internal relations* † are independent of the experiences of the individual."

Just as there are vestigial organs, so too, there may be vestigial metabolisms. That the exertion of uric acid in the mammal is such a functional relic was the view of the late Sir Wm. Roberts. It has been adversely criticised lately in "Recent Advances in Physiology and Biochemistry," but Dr. Hopkins,‡ lecturer on Physiological Chemistry at Cambridge, thus wrote of the notion in 1898, "The view is plausible, and indeed it cannot be said to be disproved, that we have in the mammalian uric acid a vestigial relic of the earlier type of excretion—something analogous with the vermiform appendix, the ductus arteriosus or the ear-point." If this or any other metabolism be admitted, it is the property of inertia in protoplasm and not affectability that is in the main causally responsible for its continuance.

Human character asserts itself often very early indeed in certain cases; how frequently we read of the precocity of men of genius. Precocity is but our term for ability, intellectuality, above the average appearing so early that education can have had little or no

* *Loc. cit.* p. 187. † The italics are mine.

‡ G. Hopkins article, "The Urine." "Text-book of Physiology by British Authors," vol. ii. p. 638. (Schäfer, 1900.)

influence in producing it. Few are those cases in which "great men" have not given early proof of their future tendencies, tastes and capacities. D. G. Rossetti, we are told, without much education, "suddenly and swiftly developed into a literary character;" his environment could have helped him nothing. Still more is this true of Chatterton. The lives of the musicians supply us with many examples of this inevitable tendency to become composers, no matter that they were being trained for very different careers. What availed it that Arne, Tartini, Schumann and Henry Smart were intended for the Law—not their surroundings, but their inherited tendencies to produce music, gave us their melodies; what availed it that Nicolo Isouard and Joseph Reinagle were intended for the Navy—heredity drove them to music; what availed it that Berlioz and Kreutzer should have been physicians, music claimed them; commercial life lost an Auber, but the inertia of inheritance placed him among the makers of sweet sounds; functional inertia forced Schubert the schoolmaster to become Schubert the composer. To what environment did Shakespeare owe his transcendent inspiration, and what external conditions made Napoleon a general at twenty-six? Before there was time for environment to work upon affectability, the innate dispositions related to the complementary property had revealed themselves. Cimabue was destined for the Church, but he had to become the painter that he was; Giotto was to have spent his

days tending sheep, but he was compelled to rear the Florentine Campanile and portray all the horrors of hell upon the plaster of the Pisan Campo Santo. Michael Angelo was to have sat at a lawyer's desk, but he dashed aside the quill to make his chisel immortal; young Galileo could not become a physician because he had to reveal himself a mathematician, and Newton, trained to be a gentleman-farmer, had to become the greatest natural philosophical intellect which has ever been embodied on this planet: certainly Grantham was not responsible for it. Newton merely allowed to develop amid, at first, alien surroundings, the latent intellectual gigantism of his mental constitution. What in ultimate analysis is genius but that expression of character which is particularly independent of the environment, and, if not inherited, can never be acquired? Not that geniuses do not possess affectability—that is a totally different point. We all know that geniuses are peculiarly susceptible—to the beauty of form or of sound, the beauty of truth or the "beauty of holiness," but it is equally true that they are geniuses in spite of themselves, as it were, because their very existence is the outcome of bioplasmic inertia carrying over a particular molecular constitution from the generation before them to their own. *Poeta nascitur, non fit* subsumes it all; in the *nascitur* we have the positive side of functional inertia in inheritance, in the *non fit* we have the negative aspect, the uselessness of environmental

influences emphasised. It is not, of course, only the conscious that we inherit from the past; we may never know all that we are actually possessed of in the way of ancestral traits, memories and experiences. Just as we are able to have revived in us through memory the world of our own individual long-forgotten past, so, too, there may be stored up in us and only in dreams revealed to us, some of the world of the much longer forgotten past of the race. We are born with an ancestral memory just as with ancestral traits of habit and feature. "Unconsciously characteristic gestures and special and peculiar traits, characteristics of handwriting, and of thought itself, are transmitted from one generation to another." * Possibly an ancestral trait perpetuated through functional inertia may lie dormant for many years in the life of the individual; thus some have explained the appearance in exophthalmic goitre of the patient being extremely startled as the inheritance of the effect of a violent fright or shock received by an ancestor; it is latent for a number of years and then makes itself evident. On similar lines Professor Stanley Hall explains dreams of flying as atavistic revivals in cerebral protoplasm of memories of such a mode of ancestral locomotion (always supposing our descent is from a bird-like ancestor).† Similarly certain cases of very long sleep (narcolepsy) of weeks or months, have been explained as the

* M. de Manaceine, "Sleep," Contemp. Science Series, p. 326. (London: W. Scott, 1897.)

† *Ibid.* p. 189.

human equivalent of hibernation in lower mammals or lower vertebrates.* The night-terrors of children and their as wonderful day-dreams and fictions are by no means always to be traced to an environmental origin. Dr. Guthrie, writing on this topic in Allbutt's "System of Medicine," relates a case "of a lady who in her desire that her children should learn nothing but what is true, banished fairy tales from her nursery. But her children evolved, from their own imaginations, fictions that were so appalling that she was glad to divert them with 'Jack the Giant-killer.'"† The physical basis of inheritance has for some time now been admitted by embryologists to be the nucleus. As Professor Wilson‡ writes, "The nucleus cannot operate without a cytoplasmic field in which its peculiar powers may come into play. But this field is created and moulded by itself. Both are necessary to development. The nucleus alone suffices for the inheritance of specific possibilities of development." Summing up on the subject of inheritance this author thus expresses himself,§ "Normal development is in a greater or less degree the response of the developing organism to normal conditions. But neither can we regard specific forms of development as directly caused by the external conditions, for

* M. de Manaceine, "Sleep," Contemp. Science Series, p. 326. (London: W. Scott, 1897.)

† Leonard Guthrie in Allbutt's "System of Medicine," vol. viii. p. 227.

‡ E. B. Wilson, "The Cell in Development and Inheritance," p. 327. (Macmillan, 1898.)

§ *Ibid.* p. 326.

the egg of a fish and that of a polyp develop side by side in the same drop of water under identical conditions, each into its predestined form. The character of the response is determined not by the stimulus, but by the inherited organisation."

CHAPTER V

FUNCTIONAL INERTIA AS RELATED TO CONSCIOUSNESS: PSYCHIC INERTIA

At a very early period in my thinking about functional inertia as a property of protoplasm, I came to the conclusion that this inertia must be demonstrable among the phenomena of consciousness or mind. Not only must it operate within the sphere of the senses, but no psychic state whatever can really be destitute of its presence. In my first paper I said there must be an inertia of mind corresponding to that of matter at rest, as well as a mental momentum corresponding to the momentum of matter. Subsequent reading showed me that this idea had not escaped former thinkers: I found that Hobbes of Malmesbury had written, "Like water troubled, an organ of sense will remain in motion after the removal of the exciting agent; in that case the corresponding phantasm is called imagination or memory." That the term "inertia" is not used, need hardly surprise us when we recollect that Hobbes died (1679) when Newton was only thirty-seven. But everything is really in this passage; the inertia of moving particles of matter, the physical analogy with the psychic process.

The great German physiologist, Albrecht von Haller, had evidently reached the same notion in his exposition of cerebral processes, for, using the term "mutationes," or changes of cerebral substance, he thus expresses himself (translation by Huxley),* "These mutations persist for a long time after the cause which gives rise to them has ceased to operate."

In the course of reading I found that in 1885 Dr. James McKean Cattell had, as regards sense-organs, anticipated my views, for he wrote,† "Inertia is a property of our sense-organs. The molecules of the cells are only set in motion after they have been worked upon by a stimulus of a certain strength and for a certain time, and the motion continues after the stimulus ceases."

Here the subliminal stimulus and the stimulus of too short duration are alluded to: I have long viewed the insusceptibility to these as cases of anabolic inertia: "the motion continues after the stimulus ceases," this is, of course, katabolic inertia.

In my first complete communication on the subject of psychic inertia, I said:‡ "Turning now to examples in which the functional inertia involves consciousness as a factor, we have an example of inertia of katabolism in the positive after-image, the retino-cerebral and conscious effect outliving

* T. H. Huxley, "Collected Essays," vol. i. p. 215. (Macmillan, 1898.)

† J. McK. Cattell, *Brain*, vol. viii. 1885, p. 289.

‡ D. F. Harris, "On the Usefulness of the Term Functional Inertia of Protoplasm," *Glasgow Medical Journal*, April 1901.

the time of the application of the stimulus, post-stimulant retinal functional inertia, in short."

It is owing to this property of inertia in the retino-cerebral protoplasm that the beautiful modern illusions of movement in the devices known as kinetoscope (bioscope, mutoscope, &c.) are due.

The stimuli—illuminated, instantaneously taken photographs—are presented in a series with a very small time-interval between the various members: the perceptions are not serial or disconnected, but, as every one knows, are quite continuous, producing the illusion of more or less smooth movement. Thus one sees without a break, such movements as those of horses galloping, fish swimming in the aquarium, a train approaching or receding. (The flashes that often mar the effect in photographic views hastily prepared for public entertainments, are not "flicker" in the physiological sense of non-fused sensations, but are probably due to dust on the films reflecting or scattering light.)

The visual positive after-image is then a case of post-stimulant activity—of protoplasmic inertia. All the cases of colour-mixture where, *e.g.*, a sector of red followed by one of blue whirled in front of the eye gives rise to a purple, or where a disc half black and half white produces grey, are all cases of persistence of retinal impression or of after-images—katabolic psychic inertia. Sometimes the positive image gives place to the negative and the negative to the positive, and so on for some seconds in alternating fashion: this phenomenon is quite

well known to experimental psychologists. It is, in short, a post-stimulant rhythm: the two opposed metabolic phases alternating by their inertias. The physical analogy is the oscillations of the rocking-stone after you have given it its initial push, the swingings of the swing-door after a person has passed through.

This phasic alternation of states due to a single stimulus is clearly comparable with the slow, rhythmic tremors in muscle which result from the application of a single stimulus as described in chap. ii. (tremor from a "single" chemical or mechanical stimulation). There is a similar phasic alternation of states in retino-cerebral protoplasm at a certain rhythm, the so-called "periodic darkening in retinal rivalry." I * showed that the intervals of comparative light between the dark periods were of an average duration of about ten seconds.

It is a matter of everyday experience that it is not only in the sense of vision that we have after-sensations. We "feel" contacts, pressures, pains long after the irritants responsible for the sensations have been removed. We o ten cannot tell whether the offending thorn is or is not in the finger-tip, and the pain of the mote in the eye continues long after the gritty particle has been removed. Muscular and articular sensations are very prone to have after-effects in consciousness: all these are examples of katabolic inertia in sense-organs.

* D. F. Harris, "On Periodic Darkening in Retinal Rivalry." *Proc. Phys. Soc.*, Nov. 8, 1902.

Speaking of pressures applied to the skin Professor Sherrington says,* "Pressure applied to the skin evokes a sensation which does not subside—the sensation continues."

The positive after-sensation of pain persists for a much longer time than does that for touch; that is, in my terminology, the katabolic inertia of the algesic sensory apparatus is greater than that of the tactile.

As we should expect, the latent period for pain is noticeably longer than the latent period for contact or for heat and cold: we feel the contact and know that the object is very hot or very cold, some considerable time before we are conscious that these stimuli are dolorific.

These two facts then make it clear why fusion of sensations should occur more easily in tactation than in algesia; faradisation of pain-spots at 20 per second gives a continuous painful sensation, while with faradisation of touch-spots at 30 per second the stimuli are still perceived discrete.

The number of stimuli per second necessary to induce a continuous sensation is evidently inversely as the magnitude of the functional inertia of the sensory apparatus involved, thus, discontinuity is still experienced from a violin-string vibrating 1552 times per second, and a toothed wheel does not give a smooth sensation until the teeth meet the skin at between 480 and 640 times per second.

* C. S. Sherrington in "Text-book of Physiology." Edited by Schäfer, vol. ii. p. 925.

As compared with pain, the functional inertia of the tactile sensory apparatus is small.

In agreement with these considerations is the additional fact that the limen of the stimulus for pain is higher than that for touch; the touch-limen is, according to the area stimulated, from $\frac{1}{3}$ to $\frac{1}{100}$ of that for pain.

Surveying these and allied facts, Professor Sherrington feels constrained to employ the term "inertia" twice in two pages of his article on the "Skin and Common Sensation."

Thus we read,* "The inertia of the pain-apparatus and the inertia of the organs for pain seems particularly great."

I may perhaps say that I had not seen this passage when my first paper was written (1899), as vol. ii. of Professor Schäfer's "Text-book of Physiology, by British Authors," was not published until 1900.

Again Professor Sherrington writes: "The physiological apparatus for cutaneous pain, takes, as compared with other skin senses, a long time to get into movement, and when once moved takes, as compared with other apparatus, a long time to return to equilibrium." Without using the terms themselves one could not better express anabolic and katabolic inertia respectively.

In discussing the time-error in successive kinæsthetic judgments, the same author employs the

* C. S. Sherrington in "Text-book of Physiology." Edited by Schäfer, vol. ii. pp. 998–999.

same principle of explanation: "There is a tendency to undervalue the succeeding weight of the pair . . . an explanation offered is that . . . the motor organs *are still in some degree of excitement* . . . when the second impulse to lift occurs, hence more innervation is employed than is intended, and the weight is judged to move more easily." *

All these allusions to psychic inertia are partial compared with those contained in a lecture by Michael Faraday to a society in London long ago defunct known as the "City Philosophical Society." †

Faraday became a member of this Society in 1813, and in 1818 he delivered a lecture to it called, "Observations on the Inertia of the Mind."

I first saw his biography in 1903, and on reaching p. 57 I seemed there to have the sanction for my views of one of the greatest workers in modern science—Michael Faraday. His biographer evidently thought this lecture of some importance, as he fortunately gives several pretty full quotations from it. "There is a power in natural philosophy of an influence universal and yet withal so obscure in its nature, so unobtrusive, that for many years no idea of it existed.‡ *It is called inertia.*§ It tends to retain every body in its present state, and seems like the spirit of constancy impressed upon

* C. S. Sherrington in "Text-book of Physiology." Edited by Schäfer, vol. ii. p. 1023.

† Bence Jones, "Life of Faraday," p. 57. London: (Longmans, 1870.) ‡ *Ibid.* p. 268. § The italics are Faraday's.

matter. Whatever is in motion is by it retained in motion, and whatever is at rest remains at rest under its sway. It opposes every *new* * influence, strengthens every *old* * one. Is there nothing in the human mind which seems analogous to this power? Is there no spiritual effect comparable to this corporeal one? What are habits? Old prejudices? They seem something like a retention in a certain state due to somewhat more than the active impulses of the moment. As far as regards them, the mind seems to remain in the state in which it is, and the words which enunciate part of our natural law will describe exactly the effect . . . to illustrate at once the force of mental inertia, to retain the mind desirous to set about a new affair, how facile our progress when once engaged, a very little delay illustrates more or less the inertia of the passive mind, every new observation, every fresh discovery that of the active mind."

. . . "Inertia is an essential property of matter, is it a never-failing attendant on the mind? I hope it is, for, as it seems to be in full force whenever the mind is passive, I trust it is also in power when she is actively engaged. Was the idle mind ever yet easy to be placed in activity? Was the dolt ever yet willing to resign inanity for perception, or are they not always found contented to remain as if they were satisfied with their situation?"

Faraday then illustrates his meaning as regards

* The italics are Faraday's.

"mental inertia" by certain examples of activities, which in my opinion are rather to be referred to mental affectability, and continues: "Apathy will represent the inertia of a passive mind, industry that of an active mind." Later in the essay, for such, rather than a lecture, it is, he writes: "I have already endeavoured to establish the analogy between habit of industry and the inertia of a moving body. . . . I have said that the inertia of matter is continually blended with other forces which complex its results and render them apparently contrary to their cause, and also that in this respect, it resembles the inertia of the mind." There is more to the same purpose, but I have quoted enough to show that the same ideas that were in my mind in 1899 were expressed by Faraday eighty-one years previously. Until the end of 1903 I had not the slightest notion that any one, still less so eminent and exact a thinker as Faraday, had established this analogy between the inertia of matter and that of mind. I felt with increasing certainty that there must be an inertial property in living matter, the physical basis of psychic inertia. It would be easy, but unfair, not to say ungracious, to criticise young Faraday's thesis, for he was only twenty-eight years old when he composed it. He does not supply the link between the inertia of non-living matter and the inertia of the mind, which is to me now so obvious, *i.e.*, the inertia of the tissues of the living organism. But we must remember that 1818 was just about the time that

the term "protoplasm" was coined by Purkinje, and twelve years before the cell-theory was enunciated by Schwann.

Further, Faraday was not a biologist, and even if he had been, scientific views took much longer to travel from the Continent to London in 1818 than they do to-day. My point of view is, of course, biologically a very much wider one than Faraday's, for, (1) there is more than an analogy between physical and psychical inertia, and, (2) that, since inertia is bound up with the molecules of living matter it underlies all metabolism and therefore all functions both those with and those without a conscious correlate. To Faraday it was a mere analogy; matter had inertia, and the mind exhibited something which was best called inertia too, but he did not say, because he was not in a position to say, that the mind has inertia because cerebral protoplasm has inertia, and cerebral protoplasm has inertia in common with the lowliest fraction of living matter. If protoplasm possesses inertia of function, then it is not merely a matter of an ingenious analogy, but it follows causally that, since psychic phenomena have their physical basis in protoplasm, psychic phenomena must exhibit inertia. The well-marked tendency to do what has been done before, to continue doing what you have just been doing, to yield to habit, to the familiar, is nothing else than the expression of the functional inertia of psychic activity. Every day we have examples of it; some one is reading from the news-

paper to us, and the expression "thirty or fewer" is used, nine out of ten persons will read, "thirty or forty" before they notice their mistake. Oliver Wendell Holmes alleges that not one in ten people can read "Judges xv. 16" correctly; the verse is, "And Samson said, With the jaw-bone of an ass heaps upon heaps, with the jaw of an ass have I slain a thousand men;" nearly every one reads "jaw-bone" for "jaw" in the second clause. But examples could be indefinitely multiplied, for mental inertia must be as universal as mental affectability. Do not bigotry and fanaticism come under the categories of mental inertia of rest and inertia of movement respectively? Are not superstition and an unenlightened dislike to change cases of inertia of psychic rest? A volatile nature is one with but slight psychic momentum, a dogged temperament is one with much. The great obstinacy of the uncultured, and the fixed delusion of the monomaniac are cases of abnormally great psychic inertia of rest.

In the child-mind we have high affectability and little inertia; we all know how impressionable the child is, and how extremely prone to imitate: there is so little inertia of position belonging to the idea in possession of the mind that it can easily be supplanted by a new idea which has so little momentum that it can readily be turned out of its course by "some new thing." I find that both Faraday and I have included habit as due to inertia; the longer the habit has existed the less will it have of

the psychic about it: whether accompanied by much, little, or no consciousness, it is due to protoplasmic inertia notwithstanding. In a very large number of cases, habit can be regarded as "unconscious memory" * and instinct is but inherited habit. It is psychic inertia that makes one write "1906" when 1907 has been two or three days old. Instinct being thus inertial accounts for its so-called "blindness" or "fatality;" naturalists know well the limits of instinct and how full it is of momentum. Sometimes it is in the interests of a hive of bees to have a queen at once placed there, but as she is a stranger to the hive she is in most cases attacked and killed through the instinct to destroy a stranger; had she been a queen reared by the hive she would of course have been fostered and fed. Much inertia and little affectability, characterises the insects; they do a little very well, very mechanically, and in a very stereotyped manner. Thus the limits to their being taught or educated are rigid: "instinct remains in *status quo*," says Marcus in his "Monism." † Now we have already identified inertia with the maintenance of the *status quo*. The associating of inertia with habit had occurred to the naturalist Frank Buckland, when, in speaking of salmon-breeding in rivers where, owing to weirs and pollution, the salmon were expected

* Ewald Hering, "On Memory as a General Function of Organised Matter." Almanack of the Imperial Academy of Science of Vienna, 1876.

† *Loc. cit.* p. 97.

not to breed, he wrote, "The *vis inertiæ* of habit." *

By functional inertia, then, character is unfolded as the great "ground tone" of a life; that something which in certain cases—men of strong character—refuses to be acted on by the environment, is deaf to her charming, blind to her attractions, insensible to her touch. This is character, it is the non-responsiveness that constitutes the "devoted life," when once its possessor has started on any line of action, he feels himself carried on by the inertia of activity, by moral momentum. "There is something in us," writes Mr. Stratton,† "that we cannot attribute to mere environment—an inner stamp or character that makes some persons have weight with us, while the behaviour of others takes no hold." There is here a groping after functional inertia. A little further on Mr. Stratton returns to the idea; he says: "The individual is not a mere recipient . . . but has within him a power which stands over against his environment . . . now aiding and heightening its particular influence, and now resisting the suggestions which it offers." ‡ Both the concepts of affectability and functional inertia are virtually present to the author's mind in this passage. Of this I feel perfectly convinced, because in the same work Mr. Stratton actually uses the term "inertia" in my

* Life of F. Buckland, Bompas. (London: Smith, Elder, 1893.)

† G. M. Stratton, "Experimental Psychology," p. 223. (Macmillan, 1903.)

‡ *Ibid.*, p. 224.

own and Faraday's sense. Thus, where the origin of illusions is being discussed, we meet with the expression, "by sheer mental inertia we cont nue to interpret the exceptional cases as if they were regular." * In 1900 I had explained the Müller-Lyer illusion on the principle of katabolic psychical inertia.† Once again this author shows us how much the notion of inertia is present to his mind, for, still speaking of illusions, he says, "They will remain by inertia for want of an opposing force." ‡ This is not exactly how I would express it, for protoplasmic inertia maintains states in spite of opposing forces. It is, however, evident that modern psychology no less than animal and vegetable physiology cannot do without the concept of inertia. Just as in the individual character psychic inertia plays so notable a part, so too, in the national character does it not constitute as potent a factor as affectability in moulding the destinies of a race? How is it that nations have a definite course of development, maturity and decay? They rise and they fall; the Roman Empire was not the only one to do so; Babylonia, Assyria, Persia, and Greece all went through very simi'ar cycles: they grew up, they had their prime, they degenerated. Something inherent rather than as due to external conditions must have brought about this similarity of fate: someth'ng unfo!ded, came to perfection, faded away in these nations as it does in individuals.

* G. M. Stratton, "Experimental Psychology," p. 104.
† *Glasgow Medical Journal*, April 1901. ‡ *Ibid.* p. 118.

There is, in short, a national rhythm of vitality as there is an individual: there is national youth, national prime, national senility; the orderly, so-called "spontaneous" unfolding of these phases is inertial.

From all we know of Oriental races, we should be safe in assuming that their stationary position, as compared with the nations of the West, is due to their possessing so much more psychic inertia relatively to affectability than the European. This is really what we mean when we speak of the stolid Oriental, the fatalistic Hindoo, the unprogressive Chinaman. These ideas are most interestingly corroborated in a learned work on Japan, published in 1904.* Here we are told in a quotation from Herbert Spencer that "Religious Dynasties have extraordinary powers to resist change," † which is another expression for the inertia of psychic rest. Again, "Legal enactments can nowhere effect an immediate change of sentiment or long-established usage, least of all among a people of such fixity of character as the Japanese," ‡ and once more, "The old regimentation of society persists under all these surface shiftings, and the national character remains little affected;" § so great is the national psychic inertia. But additional examples of this are found throughout the work. Buddhism, it appears, spread over Japan in the ninth century A.D., displacing a very old form of religion—Shinto—or ancestor-worship.

* Lafcadio Hearne, "Japan, an Attempt at Interpretation." (London: Macmillan, 1904.)

† *Ibid.* p. 306. ‡ *Ibid.* p. 420. § *Ibid.* p. 438.

"Buddhism eventually overspread the national life, and coloured all the national thought. Yet the extraordinary conservatism of the ancient ancestor-cult—its inherent power of resisting fusion—was exemplified by the readiness with which the two religions fell apart on the disestablishment of Buddhism, 1871." * "After having been literally overlaid by Buddhism for nearly a thousand years, Shinto immediately resumed its archaic simplicity and re-established the unaltered forms of its earliest rites." Here, indeed, is psychic inertia causing the swing-back of the national pendulum after a thousand years; the national psychic rocking-stone had here a very slow swing.

The relations of national psychic inertia to inheritance—that "something" that stands over against environment—are well expressed in the following passages: † "even to-day the manners of the people everywhere still reveal the nature of the old discipline"—(Shinto): "all these ordinary actions have a charm of seeming naturalness that mere teaching seems incapable of producing:" "and this is still more true of the higher etiquette . . . particularly as displayed by women." Again, "we must suppose that the capacity to acquire such manners depends considerably upon inheritance, that it could only have been formed by the past experience of the race under discipline." While all this is true of the degree of psychic

* Lafcadio Hearne, "Japan, an Attempt at Interpretation," p. 205. (London: Macmillan, 1904.) † *Ibid.* p. 192.

inertia in the Japanese character, nevertheless, as we all know, it did not in these latter days preclude a very high degree of development of affectability towards Western ideas, and susceptibility towards intellectual stimuli from Europe. It is a warning to us not to assume that mental inertia is the characteristic only of the blockhead : it all depends on the *status quo* that is maintained.

National psychic inertia can be viewed under other aspects still ; what is it that brings it about that in London or Paris there is almost the same number of suicides, misdirected letters, houses set on fire or umbrellas left in trains every year ? As to suicide, the constancy of the figures is very striking. Morselli's exhaustive treatise on "Suicide"* demonstrates conclusively that the number of such acts as voluntary death, so far from varying widely from year to year in any given community, is remarkably constant. He says : " The proportion (of suicides) to the population is maintained regularly in each particular country from year to year : " in other words, there is a limit set. Furthermore, there are noticeable parallelisms between the numbers of suicides, homicides, marriages, legitimate births and illegitimate births in any given city ; that is, the numbers per million of the population are for each phenomenon wonderfully constant. As regards England, the ratio of the number of male suicides to that of female is, over a long period, 3 or 4 to 1 ; and that of male criminals to female, 4 or 5 to 1.

* Henry Morselli, " Suicide," Internat. Science Series, 1881.

The allusion to certain forms of etiquette being more particularly observable in the behaviour of women, may lead us to the subject of the relation of psychic inertia to sex. Long before the above-mentioned work on Japan came into my hands, I had held that through the female parent rather than through the male were transmitted those conservative tendencies which we have learnt to identify with anabolic inertia. As regards the two metabolic phases, the female exhibits relatively more anabolism than the male; this seems to be in the main conclusion arrived at by the researches of Geddes and Thomson.*

The female mind is not characterised by originality, desire for innovation or reform; history does not give us many examples of its creative powers in pictorial art, music, science, or politics; women prefer rather to follow leaders and carry out schemes suggested to them. Conventional attitudes of thought, fine distinctions in etiquette, the authority of usage, the sanction of custom—these things influence them, and by them are perpetuated from one generation to another. Even in the arts to which their activities have been so long confined, culinary processes, the concerns of the fashions of clothes and the study of the pianoforte, in none of these do they attain that degree of excellence evinced by the man-cook, the male designer of dress, and the masculine pianist.

* Geddes and Thomson, "The Evolution of Sex," Contemp. Science Series.

It is with the female sex that superstition lingers; it is women who mistake dogma for truth, it is they who revere authority, and to whom the sanction of a name, the example of a leader, is of the utmost consequence. They will take neither initiative nor responsibility; but this is what I mean by saying that, as compared with the male, they have relatively more psychic anabolic inertia. I say these things not in any spirit of disrespect, and not as characterising certain bright exceptions among women, but as describing the predominant human female type of mind or mental attitude as it has been in the past most frequently exhibited. Exceptions most certainly there have been, are now, and with increasing frequency will be in the future; hitherto we have had to describe these as women with masculine minds, with the male type of brains, of whom George Eliot may be taken as an example. In all probability it would not tend to the happiness of the race were things otherwise than the present normal for the female sex; all I contend for is that the female mental differentiæ follow from the possession by that sex of a higher degree of psychic anabolic inertia than is found in the male. This is, in the opinion of many, strikingly true in politics, so much so that the majority of radical politicians at this moment hesitate to grant the parliamentary franchise to women on the ground that, in virtue of this very mental characteristic, they would almost certainly vote on "conservative lines," that is to say for the maintenance of the *status quo*.

One of my earliest examples of psychic inertia was that of "the lack of correspondence between sensation and stimulus as formulated in the Weber-Fechner Law." I regarded the absence of response to subliminal stimuli, the ineffectiveness of supra-maximal stimuli to call forth any greater response than did the maximal, as cases of physiological inertia; as also all the non-responses on the side of consciousness to a whole series of increments of stimulus from the last sensation-producing one to the next. Once more I find Professor Sherrington expressing himself in agreement with the tenor of these views.* "Weber's Law may be a sort of law of friction in the neural machine." The same expression "friction" is used by the psychologist, Professor James. I prefer to speak of inertia rather than friction as the property of protoplasm underlying the Weber Law on account of the wider applicability of the principle of inertia to vital phenomena; although I am far from denying that certain manifestations of vitality could not be as appropriately *described* in terms of friction. As will be apparent in the last chapter, molecular friction may be the result of the still more primitive property of molecular inertia; in any case no one would deny that, as properties of molecules, they are closely related.

We are prepared for the generalisation that those mental tendencies that are inherited are preformed capacities and preadjusted endowments not

* C. S. Sherrington in "Text-book of Physiology." Edited by Schäfer, vol. ii. p. 932.

dependent on the environment nor owing anything to it. They are of the most varied description from sublime genius to imbecility, from the heights of religious rapture to the depths of insanity and crime. By psychic inertia, instincts, capabilities, and incapabilities, predispositions to all manner of activities and non-activities good and bad, are carried over into the next generation where they unfold themselves and maintain themselves not only in non-accordance with the environment but often in opposition to it. The environment in matters psychical always includes, is chiefly constituted by, education. Educability is psychic affectability, in-educability is psychic functional inertia. It is this that Professor Ribot alludes to when he says that "heredity has set a limit to the education of the negro," * and it sets it to that of many others besides. This is psychic inertia expressing itself *via* heredity as limit-setting, a mode with which we are familiar. It is the misfortune not the fault of the negro, and so with all those who have inherited disabilities. Such educational disabilities may belong to the individual, the class, the race. Something of this was in Faraday's mind when he wrote in his lecture on mental inertia,† "This is, of course, equivalent to an avowal that there are natural disturbing forces of the inertia of the mind, and that an irregular, a retarded, or even an inverted progression must at times take place in knowledge and morality

* Ribot, "Heredity," p. 327. (London: H. S. King and Co., 1875.)

† *Loc. cit.* p. 278.

without any gross charge being incurred by mankind." This is now being widely recognised; the thief by instinct, that is, by heredity, the man who inherits the unstable brain and the tendency to insanity of mind, the youth who is the victim of hereditary alcoholism—these are being pitied, helped, studied, anything but blamed at the present moment. There appears to be no form of mental aberration, of emotional abnormality, that may not be inherited (Ribot): * what seems, in any given individual to be so spontaneous, may really be parentally derived or even be an atavism to a remote past. Thus the educationist and the moral teacher stand aghast before psychic inertia and ask if modern science, the physiology and psychology of to-day, can merely groan in the hopelessness of an enlightened fatalism. Such is happily not its position; the hereditary criminal or drunkard is not, of course, absolutely destitute of psychic affectability, although in these days it is his psychic inertia which, under other names, has been more particularly recognised and studied. But, indeed, such cases are hopeless enough; the imbecile, the weak in intellect, the hereditarily depraved! with these education has the impossible task of being asked to make bricks out of the granite masses of functional inertia with only one or two straws of affectability thrown in. Still, all cases are not absolutely hopeless, though the psychologically trained teacher

* Ribot, "Heredity," p. 86. (London: H. S. King and Co., 1875.)

knows well the inexorable limits set by psychic inertia. Limits all psychologists recognise; Ribot writes* of the organism's "limited capacity for pleasure and pain;" intellectual limits are as notorious: wise is that man who early recognises his own.

Thus such a recent writer on "Education and Heredity" as J. M. Guyau, is fully alive to the mental inertial factor as *the* great difficulty of educationists. He assigns to a moral characteristic, good or bad, five generations through which to persist before it is eliminated,† but a few thousand years ago the Bible set the limit at the third or fourth.

Monsieur Guyau is very explicit as regards inherited disabilities and limits: "many philosophers and men of science now believe that education is radically powerless when it has to modify to any great extent the radical temperament and character of the individual; according to them a criminal as well as the poet, *nascitur non fit*—the child's whole moral destiny is contained in it while yet unborn, and in later life this destiny develops itself relentlessly." Had I seen this passage when first putting together my views on heredity and consciousness as related to functional inertia, it would have confirmed me very strongly, for I could scarcely have had them better expressed. From my point of view, however, they are incomplete only because the relation of this fatality of preadjustment is

* Ribot, "Heredity," p. 86. (London: H. S. King and Co., 1875.)

† *Ibid.* Preface, p. 23.

not attributed to a fundamental property of all organic beings.

Inherited endowments are of the most varied nature, some eminently useful in the struggle for existence, others as conspicuously without any obvious significance. Take as a type of the latter those very curious, indissoluble and apparently inexplicable associations known as "coloured concepts," what I have called cases of psycho-chromæsthesia. I have collected * a considerable number of examples of these coloured concepts, and arrived at the negative conclusion that they are certainly not environmentally produced. In some cases they were preformed, appearing to very young children as ready-made associations. As far as I can gather, they are never acquired but always innate: they are not synæsthesial such as coloured hearing (*Audition colorée*, as when a certain note on the organ or violin appears blue or purple), but occur when every letter of the alphabet, every hour of the day, every day of the week, every month of the year and so on, seems, on its name being visualised, to be written or printed in colour: they are in my terminology eminently inertial.

Still more extraordinary as revealing the innate contents of the human mind, are those most curious cases of certain persons during attacks of insanity or in hypnosis using words of a character absolutely

* D. F. Harris, "Psychochromæsthesia and certain Synæsthesiæ," *Edinburgh Medical Journal*, December 1905.

foreign to their normal life and experience. Well-authenticated cases have been recorded of young girls of the upper classes who, on becoming insane, have given utterance not only to oaths but to profane and obscene expressions (*coprolalia*) the meaning of which they could not possibly comprehend and which they certainly had never once heard uttered. On this feature in cases of nymphomania *cf.* Maudsley.* This conduct of young ladies who have become insane is comparable with that of old gentlemen, who, after a life of decorum and moral rectitude in matters of sex, will suddenly develop propensities to indecency and sexual immorality totally out of keeping with their past training and behaviour. This form of senile degeneracy is well known to those versed in psychological medicine : it is of purely non-environmental origin, and therefore the expression of some latent disposition related not to affectability but to functional inertia.

The scientific study of the insane abounds with examples of psychic inertia. Under the category of periodicity we have *folie circulaire* itself where, in a definite rhythm, the patient is sane and insane alternately ; this has little reference to the environment ; if it was through his environment that he became insane, through what environment has he now become sane again, for his environment has not altered ?

* Henry Maudsley, "Body and Mind," p. 83. (London : Macmillan, 1870.)

What is melancholia but a great diminution of affectability coupled with an abnormal increase of psychic inertia? For, as Professor Ribot* writes, "the special mark of the pure type of apathetic is inertia;" that is to say, it is not merely a diminution of affectability. On the physical side it is well known that the bodily functions of melancholics become exceedingly depressed, little bile is secreted, constipation is the rule, all is stagnant, remiss, inert.

Again the "insane impulses" so powerful, so whimsical, so sudden in their exhibition can scarcely be regarded as due to environment. Rather than examples of affectability they would be cases of what Ribot alludes to in connection with a slightly different yet closely allied activity as "desire anterior to all experience, it acts as a blind force, it is a *vis a tergo*, it must necessarily act at once."†

Finally, innate ideas, if they exist, inasmuch as they are inherited and anterior to experience, must be related to psychic inertia and not to psychic affectability. It is fortunately not my duty to decide whether they exist or not, but if they do, the metabolic mechanism constituting their physical substratum cannot be very different from that underlying any of the other inherited psychic capabilities, tendencies, aptitudes, or possessions. My point at this present moment is, that innate ideas, like all other innatenesses, not being *ex hypothesi*

* Ribot, "Psychology of Emotions," Contemp. Science Series, 1897, p. 389.

† *Ibid.* p. 442.

related to external conditions, must be an expression of psychic functional inertia. In matters psychic we have functional inertia once more playing its part in those curious but well-authenticated cases of hysterical or hypnotic anæsthesias. They are very often hemi-anæsthesias: the hysterical patient or the person hypnotised declares he is blind in one eye, deaf in one ear, insensitive on one side of his body; or cannot distinguish port wine from castor-oil. Dr. Waller * in alluding to the cerebral cause in this condition uses the words, "some functional disorder or incapacity;" clearly the opposite of affectability is meant. There is a psychic functional inertia established as part of the hypnosis or the hysteria, how, we know not. Where Heidenhain has used the term "inhibition" as designating the withdrawal of attention and other phenomena of defect in hypnosis, it seems to me that cerebral functional inertia more nearly describes the molecular state underlying the undoubted psychic inertia of the state of profound in-attention or abstraction observed. As Heidenhain † remarks, "the hypnotised person is distinguished from the normal in that, for him, the liminal value of stimulation is extraordinarily high:" molecular inertia must here have been the causal condition to bring this about.

* A. D. Waller, "On the Functional Attributes of the Cerebral Cortex." *Brain*, vol. xv. 1892, p. 365.

† R. Heidenhain, Hypnotism Translation. (London, 1892.)

CHAPTER VI

THE GENESIS OF FUNCTIONAL INERTIA IN THE INERTIA OF THE NON-LIVING

It is long since workers in the field of physics attributed inertia to the *molecules* of matter : inertia is assumed to belong to them as much as it does to masses, so that in the realm of the non-living we have molar inertia and molecular inertia. But a study of molecular physics has compelled such an experimentalist as Professor J. C. Bose to attribute *affectability* to non-living substance. That is to say, by using certain kinds of wires and certain kinds of solutions under appropriate stimuli (torsions, radiant energy, &c.), this worker obtains *responses*, in these cases alterations of E.M.F. (production of electric current) between two points of the wire or two portions of the solution under investigation.

Working in this fashion, Professor Bose obtained latent period (to the physicists, latency in response is known as " lag."), staircase effects, summation of effects, post-stimulant effects, the phenomena of fatigue, diphasic variation, effects of an optimum temperature and of poisons, all on absolutely non-living matter.

Some of these phenomena are clearly due to molec-

ular affectability, and some are as clearly due to molecular inertia or "molecular sluggishness" as Professor Bose distinctly states.* How can staircase or "treppe" effects in living matter be better described than by saying that the protoplasmic inertia is being overcome more and more effectively at each response until it is no longer obvious? Certainly it is molecular inertia that in the non-living is responsible for the "treppe" phenomenon at all.

If then it can be so satisfactorily proved by the same method that is used for living matter, that non-living matter possesses both the properties of molecular affectability and molecular inertia, we must be prepared to attribute molecular inertia to living matter, seeing that we have already recognised that it possesses affectability. In other words, seeing that affectability is a property not possessed by living matter alone but must be attributed also to the non-living, so analogously, since molecular inertia is demonstrable in the non-living it is extremely probable that it exists also in the living.

Fatigue in metals is now a commonplace with mechanical engineers; † they are compelled to use the physiological term as best expressing their meaning. Now we have seen the relationship of fatigue to functional inertia, viz., that the former is

* J. C. Bose, "Response in the Living and Non-living," pp. 104, 109. (Longmans, 1902.)

† *Cf. Nature*, vol. lvii. 1898, p. 58, for the microscopy of "fatigued" steel.

a state pre-eminently indicative of the existence of the latter. Dr. Bose speaks of "lethargic wires."

Once more: we find the notion of "fatigue" applied to non-living matter by no less an authority on physics than Lord Kelvin in his article on "Elasticity" in the *Encyclopædia Britannica*.* It was found in experiments at Glasgow that wires caused to oscillate by torsion came to rest in a shorter time after many previous torsional oscillations than if they had been rested before being submitted to the torsion. Wires that had had a Friday to Monday rest were on Monday much "fresher," *i.e.*, capable of performing more oscillations than wires which had been kept oscillating from Friday to Monday. Summing up his Lordship says, "there is in elastic solids a molecular friction" which is to be regarded as the cause of "fatigue of elasticity." This is molecular fatigue in the non-living recognised by a writer free from any biological bias.

As might be expected, the molecular parallelisms between the non-living and the living are most striking when the non-living is some form of *chemical* mechanism, such as the "sensitive cell" of Bose.† Using an arrangement of brominated silver plates —the photo-electric cell—and the galvanometer to record changes of E.M.F., it was shown that every kind of response characteristic of a vital organ such as the eye, could be obtained from the non-living mechanism. On this point, Professor

* W. Thomson, article on "Elasticity," *Encyclopædia Britannica*, 9th edition, vol. vii. p. 802. † *Loc. cit.* p. 148.

Bose sums up,* "In both we have under normal conditions 'a positive variation' (of the injury or resting current, or current of reference), in both the intensity of response, up to a certain limit, increases with the duration of illumination, in both there is comparatively little fatigue, the increase of response with intensity of stimulus is similar in both, and finally even in abnormalities—such as reversal of response, preliminary negative twitch on cessation of illumination, and decline and reversal under continued action of light—parallel effects are noticed." Professor Bose does not in this *résumé* include a phenomenon he had recorded in his experiments on the photo-electric cell, viz., electric after-oscillations strictly comparable with after-action (after-image) on the retina when light was shut off. Clearly this latter is due to the inertia of movement of molecules in the "cell" and in the retina respectively—katabolic inertia—as truly as the opposite phenomenon, the imposition of limits, is due to inertia expressed functionally as an insusceptibility.

Particularly curious is the parallelism between "dosing" a tin wire with small and with large amounts of K·OH and the well-known difference between the effects of large and small doses of certain drugs, *e.g.*, alcohol: small doses increase the electrical responses, while larger depress or abolish them.†

From the evidence we have examined in the foregoing pages we have strong grounds for believing

* *Loc. cit.* p. 167. † *Ibid.* p. 146.

that the property of inertia in protoplasm is a molecular affair—neither more nor less dependent on molecular structure than is affectability. Just as the property of gunpowder to explode when a spark falls on it is due to its molecular structure expressed here as an affectability—explosive susceptibility—towards sparks as stimuli, so the *failure* of cordite to explode when ignited is as much due to its molecular structure expressed here as a non-affectability towards sparks or flames ; but this latter might be pefectly well called the *explosive* inertia of cordite. It has affectability towards an appropriate stimulus, *e.g.*, concussion. Just as no organism is all inertness so neither probably is any non-living mass.

There are, of course, certain differences between the affectability of the non-living and of the living. One of these is noted by Donaldson in his work, " The Growth of the Brain." * He points out that the same force of explosion of gunpowder will be the result of the application of either a small spark or of a huge flame, whereas, within limits, the discharge from a nerve-cell varies in intensity according to the intensity of the stimulus impinging on it.

So in sensory stimulation : the effect on the retina is, within limits, the greater according as the stimulus is greater ; the light from a glow-worm produces much less retinal disturbance than the electric flash.

There is a superior limit set by functional inertia : the supra-maximal stimulus produces no more effect

* Donaldson, " The Growth of the Brain," Contemp. Science Series, p. 277. (London : Scott.)

than the maximal whether in retina or in muscle. Heart-muscle, however, resembles the chemically explosive living matter in respect of its "all or nothing" behaviour: a weak stimulus as effectually as a strong will bring out the maximal force of systole. The inertial manifestations of cardiac muscle, as we have seen, are very pronounced, and this non-correspondence between strength of stimulus and energy of response is but one more expression of them.

If affectability then is ultimately (causally) based on some molecular grouping peculiar to living matter, so is functional inertia neither more nor less so: functional inertia is no more physical than or is as physical as affectability.

In this realm of properties behind the phenomena of living matter in which I wish to consider all the diverse vital phenomena as dependent on *two* fundamental properties of protoplasm, the concepts "vital" and "bio-chemical," come to be synonymous. When to-day we assert that secretion, absorption, and movement are "vital" phenomena, the outcome of affectability, we do not mean by vital anything more, physico-chemically, than complexity of molecular groupings in protoplasm; and similarly, when I attribute latent period, refractory period, and other insusceptibilities (all equally "vital" phenomena) to the property of inertia in protoplasm, I mean that they also are due to some other and complementary complexities of molecular grouping in the living stuff.

It is, therefore, highly probable that the property

which we have learned to call protoplasmic affectability always expressible as a transformation of energy, has had its genesis æons ago in the very primitive affectability of the non-living ; and similarly, that that other property which we know to exist in non-living molecules, their inertia, is the causal antecedent of that inertia which we must henceforth learn to attribute as a property to the molecules of living matter.

As Maudsley has boldly said, " Life is not a contrast to non-living nature, but a further development of it." * He reports Coleridge as having asserted " that the division of substances into living and dead, though psychologically necessary, was of doubtful philosophical validity." We seem justified in drawing up the scheme shown on the opposite page.

I would like to allude to a notion, which figures a good deal in biological literature, viz., that of " internal stimuli." When some observer or another finds some reaction clearly not related to environmental conditions (external stimuli), he writes it down as due to " internal stimuli." Some writers mean by internal stimuli such things as blood, lymph CO_2 or O_2—these I put on one side in this criticism : they are as *external* to the living cell-structure as is any environmental condition. It seems to me that the continued use of this expression is not conducive to clearer thinking.

We have seen that in Biology we have to deal with living molecules related to stimuli (" external

* H. Maudsley, " Body and Mind," p. 163.

conditions ") by means of two properties which are, in ultimate analysis, based on the particular inter-relation at any one moment between the two metabolic states in the protoplasm. A stimulus may be almost anything except a state of the molecules themselves.

Matter.	Molecular Grouping.	Two Attitudes towards Stimulus.	Phenomena.
Non-living.	More or less complicated.	(1) Affectability in virtue of which it exhibits .	certain (galvanometric) responses.
		(2) Molecular inertia in virtue of which it exhibits	no response, latent period, fatigue, superior limits, &c.
Living.	Extremely complicated.	(1) Protoplasmic affectability in virtue of which it exhibits .	certain vital responses, activities, transformations of energy.
		(2) Protoplasmic functional inertia in virtue of which it exhibits	physiological insusceptibility, refractory and latent period, spontaneous rhythm, preservation of type: heredity, disregard of environment, &c., limits, &c.

The stimulus is anything which causes or tends to cause the molecules to rearrange themselves in space or to be the means of transforming energy, but the rearranging of the molecules and their transforming of energy are not stimuli, but the effects of stimuli. When phenomena are credited to "internal stimuli," these metabolic transformations themselves are regarded as the stimuli.

Automatic and spontaneous activities and rhythmical phenomena are said to be due to "internal stimuli." Now what are these stimuli if they are not the metabolic transformations of the molecules which physico-chemically underlie the phenomena ? Molecules we know, their two-phased metabolism we know, their properties we know, their external stimuli we know, but what are "internal stimuli" over and above all these ?

I expect that what is often meant by the expression "internal stimuli" is that certain molecules in a state of agitation (katabolism ?) act on or induce other neighbouring molecules to become similarly agitated. In other words, vibrations are propagated through groups of molecules possessing not too much inertia.

Molecular vibrations in one portion of an affectable mass may in this way be regarded as the stimuli for other less agitated portions, and this is the essence of Hering's view of metabolism, viz., that anabolism induces katabolism in space and in time and *vice versa :* but the question has still to be answered what was the stimulus responsible for the original vibrations of the molecules first agitated ? What agency produced the initial disturbance ? Their own metabolism : this is tautology : they are found to be in a state of metabolic activity induced by their own metabolic activity—this is neither logically correct nor biologically common sense : it is, however, precisely what some authors affirm, although, of course, in other words. It is particularly automatisms and

rhythmical activities that are supposed to be due to "internal stimuli," *e.g.*, rhythms of Medusæ. When Professor Ribot * speaks of "reactions . . . coming from within not from without" he means much the same as do those who use the term "internal stimuli." The phrase is objectionable because all reactions (responses) are from within, though stimuli are from without.

All "reactions" are from within; but whereas some are known to be definitely and strictly related to some change in external conditions (stimuli) and are, therefore, responses related to the property of affectability, others are as clearly not definitely or directly related to such conditions and are, therefore, to be regarded as related to anabolic or katabolic inertia. As a term, "internal stimuli" is superfluous; if they are not really external stimuli, then internal stimuli are either, (1) one or other of the properties of the living molecules or else, (2) they are the molecules themselves in the condition of predominent Anabolism or Katabolism respectively.

If the former is meant, then stimuli are confused with properties of living matter; if the latter, stimuli are identified with molecules in activity. Now most certainly there are such things as stimuli which are molecules in activity, *e.g.*, the nerve-impulses as they impinge on muscle or gland, but these, as related to muscle or gland, are as external to the affectable tissues as is an electric discharge or a mechanical shock.

* Ribot, Psychology of the Emotions, p. 399.

As for the "automatic" and rhythmical phenomena, which internal stimuli are supposed to "explain," we have seen they are activities resulting from the possession by the protoplasm of little affectability and much inertia: partly through responses to certain stimuli and partly by disregard of others in virtue of these *two* properties, the active living matter goes through a cycle of metabolic phases—the visible or recordable aspect or outcome of which is the automatism or rhythm in question.

In the same way to "nutrition" or "nutritional states" are by some writers credited the phenomena which by others are credited to internal stimuli. Now this nutrition in more precise language means predominant anabolism (assimilation) in consequence of plenty accessible nourishment for the protoplasm: as long as food is present, it will assimilate some of it—this is life, of the very essence of life, only living matter can do this. How does it do it? By possessing the property of affectability towards food as stimulus: the living stuff "responds" to the presence of food in its vicinity by engulfing it—assimilating it—performing anabolism—this is life, this is what the non-living cannot do.

The relationship between food as stimulus and the living biogens, in virtue of which food is assimilated and no anti-bodies formed, is called affectability, it is of the essence of livingness: the non-living cannot assimilate although it is affectable.

But anabolism cannot proceed indefinitely or alone; it is concomitant with katabolism; it leads

up to it : we eat to work—the fed and unexercised horse will become " too fresh," as it is called, will become "spontaneously" active, and unless driven or ridden will kick his stall down.

In this sense anabolism is the " internal stimulus " for katabolism, only *in this sense* the high state of nutrition is a stimulus. On analysis, however, there is no new idea here : by the too great building up of biogens their instability is brought about, and the unstable molecules " topple over " on the advent of a stimulus so excessively minute as to be practically negligible, certainly extremely difficult of detection. Much spontaneity is of this order metabolically.

We have seen that one of the expressions of functional inertia is the setting of limits : this point is worthy of attention here. There is nothing to prevent a crystal growing indefinitely large if continually supplied with sufficient soluble material for its accretion, but there is a very definite limit set to the growth in bulk of the organism. Trees do not, like the Tower of Babel, grow up until their tops reach heaven ; protoplasmic inertia precludes such infinite affectability ; as Maudsley says of the organised being, " it cannot overstep the laws of its form. The plan is the law, and the law is not something outside, but inherent in it." * This " inherent " something, this " law " that is opposed to the environment, is protoplasmic inertia once again setting limits.

* H. Maudsley, Body and Mind, p. 166.

SUMMARY

(1) In the preceding pages we have seen, in the first place, that functional inertia is as fundamental, primary and primitive a property of protoplasm as is affectability.

The one cannot be called more fundamental than the other. The phenomena of vitality cannot be adequately conceived of in terms of one of these properties exclusively.

(2) While the two aspects of functional inertia are only analogous with the inertia of mass of matter at rest and of matter in motion (momentum) respectively, it is extremely probable that molecular inertia in the non-living is the physical starting-point of the inertia of biogens.

It seems that we must attribute molecular affectability and molecular inertia to certain portions of non-living matter, and, therefore, it is extremely probable that protoplasmic inertia has had its genesis in the realm of the non-living.

If, on the one hand, we thus extend the notion of affectability to the non-living, there is no logical ground for refusing to extend the idea of inertia to the molecules of the living.

This does not by any means obliterate the broad lines of separation between non-living and living matter: there are other *differentiæ* between them, *e.g.*, assimilation, and excretion of CO_2.

(3) The significance of the possession of functional inertia seems, in many cases, to be in the direction

of preserving the protoplasm from excessive activity, whether it be physiological insusceptibility or a disregard of environmental changes, or the establishment of limits beyond which no stimuli are effective, or in the institution of a slow rhythm for a very rapid one necessarily tending to produce fatigue, or in intermittent discharges in place of a continuous discharge of energy necessarily tending to exhaustion.

In the case of dried seeds, rotifers, &c., in " latent life," the high degree of inertia towards any one stimulus is a means of preserving the individual from death and decomposition without at the same time permitting the exhibition of vital activity (*cf.* Hibernation and Narcolepsy in higher animals) : it is a biological compromise.

By its being the factor underlying the mechanism of inheritance, habit, instinct, and unconscious memory, functional inertia is as important as affectability in educability and therefore in the theory and practice of education.

Finally, I have not introduced the conception of functional inertia as a property of protoplasm into Biology to complicate the theoretical aspect of livingness ; on the contrary I have been repeatedly assured by botanists, physiologists, pathologists, psychologists, and educationists that my postulating of this property had done distinct service as an illuminating influence in their respective domains of study.

I was urged to put my views down more fully and in a form more accessible than is possible

in any paper or communication to a learned society.

I found that nothing short of attributing to protoplasm a property in addition to affectability would provide for the adequate theoretical explanation of many phenomena both observed in nature and obtained by experiment.

I found that the results of the possession of such a property had been more or less clearly perceived by many writers beginning with Hobbes and Faraday, and, nearer our own time, by Professor Adami, Dr. Cattell, Monsieur Guyau, Dr. Charles Mercier, Professor Mosso, Mr. R. A. Robertson, Professor Ribot, Professor Schäfer, Dr. Sharkey, Professor Sherrington, Dr. Stratton and Dr. Waller, by all of whom even the *term inertia* itself was used as characteristic of living matter under certain conditions.

I found that certain phenomena could be properly thought of as depending only on the possession by protoplasm of a real or positive property—functional inertia—and not merely on the diminution or the absence of affectability.

No one had, however, gone so far as I felt justified in going, viz., to attribute the property of inertia to the biogens or living molecular constituents of protoplasm. I felt that the time had come to get beyond mere analogies between the inertia of masses and the functional inertia of biogens, and to attribute to these biogens a property other than that of the power to respond to a stimulus.

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